# INFLUENCE OF LAND USE AND THE CONSERVATION RESERVE PROGRAM ON NATIVE INVERTEBRATE POLLINATOR COMMUNITIES IN SOUTHERN HIGH PLAINS WETLANDS AND UPLANDS

By

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INFLUENCE OF LAND USE AND THE CONSERVATION RESERVE PROGRAM ON NATIVE INVERTEBRATE POLLINATOR COMMUNITIES IN SOUTHERN HIGH PLAINS WETLANDS AND UPLANDS

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Abstract: Numerous studies have documented that invertebrate pollinator services are critical to the world economy. The Southern High Plains (SHP) of Texas was identified as an area where the demand for pollination service may exceed availability in the future. Therefore, in 2013 and 2014, we collected pollinators and anthophiles using blue vane traps and sweep nets in cropland, conservation land, and native grasslands of this region because there is a lack of data on pollinator occurrence. Our objective was to determine how the predominant land uses affect invertebrate pollinator abundance, species richness, and diversity, and more specifically, if the Conservation Reserve Program (CRP) can provide quality habitat for pollinators in the High Plains. We also examined how playa wetlands embedded within these land uses contribute to pollinator habitat. Playas are refugia of diversity in an arid landscape and threatened with loss from sedimentation and land conversion. Blue vane trap and sweep netting showed that CRP had consistently lower total abundance, overall species richness, and diversity than native grassland and cropland, which were similar. With blue vane traps, when land type was a significant effect, uplands had higher abundance, richness, and diversity than playas. However, sweep net data showed that pollinators frequently foraged on wetland plants. We then evaluated vegetation characteristics of the three primary SHP land uses and their embedded playas. AIC model selection and path analysis showed that percent grass and duff cover of the land uses were the primary factors influencing pollinator abundance and richness. CRP had the most adverse effect on total pollinator abundance and richness, likely because of the high percentage of dense, non-native grasses and low floral cover. CRP could be improved by creating seed mixes that include native grasses and native flowering forbs to replace existing non-native grasses to enhance the availability of nesting sites for solitary bees and expand floral resources. Native grasses in CRP uplands will also allow for a more natural hydrology of the CRP playas and encourage growth of wetland plants. Implementing buffers strips around playas seeded with native grasses and flowering forbs could serve as valuable refugia for pollinators and protect cropland playas from sedimentation.

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# INTRODUCTION

The value of pollinators to the world economy is immense. Gallai et al., (2008) determined that in 2005, the value of insect pollination to world agriculture was € 153 billion. Pollinators are also necessary for the persistence of native plants, food security, and human health (Council 2007, Klein et al. 2007, Potts et al. 2010, Ellis et al. 2015). In the 1990s, scientists became aware that many species of native invertebrate pollinators were in long-term decline, or their services were scarce (Allen-Wardell et al. 1998, Steffan-Dewenter et al. 2005, Biesmeijer et al. 2006, Council 2007, Gallai et al. 2009, Potts et al. 2010). The issue reached critical status in 2006 when beekeepers in the United States began reporting massive die-offs of honeybees (*Apis mellifera*) (Stokstad 2007, EPA 2017).

In response to growing concern for how a decline in pollination service could affect the agricultural economy (Morse and Calderone 2000, Steffan-Dewenter et al. 2005, Calderone 2012a), the U.S. White House issued a Memorandum on Creating a Federal Strategy to Promote the Health of Honeybees and other Pollinators (The White House 2014). One of the goals was to increase the quality of pollinator habitat in the US Department of Agriculture's conservation programs, specifically the Conservation Reserve Program (CRP) (The Pollinator Health Task Pollinator Health Task Force 2015).

The CRP is the largest land conservation program in the United States, valued at approximately $ 2 billion a year since 1985. It is a Farm Bill program, administered by the United States Department of Agriculture Farm Service Agency (USDA FSA).

The Southern High Plains (SHP) is one of the most intensively cultivated regions in the Western Hemisphere (Bolen et al. 1989). The original native upland habitat was shortgrass prairie, and that which has not been cultivated was grazed by livestock (Smith and Haukos 2002, Smith 2003), primarily beef cattle (National Agricultural Statistics Service 2016). Because of the intensive agriculture and high erosion potential, the SHP receives considerable funding through the CRP (Farm Service Agency 2017). The nine SHP counties targeted in this study (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock, and Swisher) (Figure II.1) encompass approximately 2,353,522 ha. The climate is dry steppe (Smith 2003). The mean daily temperatures from April - September in Amarillo, TX, the northern portion of the sampling area, was 13.50°C – 20.83°C, and average precipitation for April – September was 5.33 cm – 4.88 cm (National Weather Service 2017a). Lubbock, TX is in the southern portion of the sampling area and April – September temperature ranges from 15.83°C – 22.06°C, and average precipitation for April – September was 3.58 cm – 6.38 cm (National Weather Service 2017b). Precipitation comes primarily from thunderstorms in May – June, and September - October and can be highly variable (Smith 2003). Playa wetlands are the keystone ecosystem in the SHP (Haukos and Smith 1994). Playas are shallow, depressional, recharge wetlands characteristic of prairie and semi-arid habitats formed and maintained by wind, waves, and dissolution (Smith 2003). Playas are approximately

3% of the SHP land base, providing biodiversity refugia (Bolen et al. 1989, Haukos and Smith 1994, Smith and Haukos 2002).

A study by Koh et al. 2016 identified several counties within the study site as areas where the demand for pollination service in the future will exceed supply. There is little information on invertebrate pollinator species and potential pollinators currently present in the SHP except for field guides with general distribution maps. Therefore, because of lack of data on pollinator occurrence, in 2013 and 2014, we collected pollinators and anthophiles using blue vane traps and insect nets in cropland, conservation land, and native grasslands.

This study compared the abundance, richness, and diversity of pollinator communities in nine counties of the SHP of Texas, and how these communities differ among the three major land uses of the area. Our goal was to determine how effective CRP was for pollinator habitat relative to the other land uses and to determine how the program could be improved to meet the goals of the Presidential Memorandum. Additionally, we examined the influence of playa wetlands embedded in these land uses on pollinator communities. Playas are shallow, depressional, recharge wetlands characteristic of prairie and semi-arid habitats formed and maintained by wind, waves, and dissolution (Smith 2003). Many species of wildlife in the SHP are dependent upon playas because they comprise the majority of the remaining native habitat (Haukos and Smith 1997). Wetland flowering forbs have potential to serve as a source of forage for pollinators.

Drs. Loren Smith and Scott McMurry wrote the grant for this project and proposed the research questions and designed the statistical analysis in Chapters II and III. They are co-authors on all chapters. Chapter II provides a checklist of all of the pollinator, potential pollinator, and anthophile species collected in 2013 and 2014. It also provides a comparison of the insects captured in blue vane traps and sweep nets. Several individuals contributed to the identification of the insects including Samuel O'Dell and Mimi Jenkins of United States Geological Survey Northern Prairie Wildlife Research Center (USGS NPWRC), Lisa Overall and myself. Lisa Overall is a co-author for Chapter II. Chapter III compares abundance, richness, and diversity of pollinators captured in blue vane traps and sweep nets in cropland, CRP and native grasslands. Chapter IV compares vegetation characteristics of each land use including percent flowering forb cover, non-flowering forb cover, grass cover, bare soil, embedded litter, woody litter, duff, mean vegetation height and vegetation height variance. We attempt to estimate causal connections between vegetation characteristics, land use, and pollinator abundance and richness. With data from sweep net samples, we identify the flowers on which pollinators are feeding so that we can make recommendations for a CRP seeding mix. I designed the research questions and statistical analysis in Chapter IV with guidance from Dr. Smith.

# CHAPTER II

## POLLINATORS (INSECTA: APOIDEA) AND ANTHOPHILES OF THE SOUTHERN HIGH PLAINS (LLANO ESTACADO) OF TEXAS


### ABSTRACT

Pollinators are necessary for the persistence of native plants, food security, and the agricultural economy. Maintaining or restoring pollinator communities will not be successful unless we have adequate baseline data on which to measure our progress. We also need adequate sampling methods. There is a lack of data on pollinator occurrence in the Southern High Plains of Texas; therefore, in 2013 and 2014, we collected pollinators and anthophiles using blue vane traps and insect nets in cropland, conservation land, and native grasslands. With capture methods combined, 74,358 insect specimens were collected; 63% of the specimens were Hymenoptera, 28.6% were Coleoptera, 4.5% were Diptera, 2.3% were Lepidoptera, and 1.6% were of other orders. There was a difference in the frequency of insect orders captured between blue vane traps and insect nets; net collection resulted in a higher percentage of dipterans and coleopterans than blue vane traps while blue vane traps had more hymenopterans. Past studies support that blue vane traps are an effective method of trapping bees and our results demonstrated that they are also effective in attracting some families of anthophilous Coleoptera and Diptera. However, insect nets captured several species of Diptera and Lepidoptera that were not identified in blue vane traps, demonstrating the value of multiple collection methods in accurately detecting richness in a region. This study documents pollinator, potential

pollinator, and anthophile species present in a highly altered landscape and is the most comprehensive list of pollinators and anthophiles in this region to date.

## INTRODUCTION

Pollinators are necessary for the persistence of native plants, food security, and the agricultural economy (Council 2007, Klein et al. 2007, Potts et al. 2010, Calderone 2012a). There is, however, a paucity of data on pollinator occurrence in the SHP of Texas Plains except for field guides with general distribution maps, especially the Southern High Plains (SHP) of Texas. To better understand the status of pollinators in the SHP, our objective was to examine diversity, richness, and abundance of native pollinator communities in the three dominant land uses in the SHP; cropland, Conservation Reserve Program (CRP) lands, and native grassland. The CRP is the federal government's largest land conservation program (Congressional Research Service 2012), and its purpose is to provide rental payments and cost share assistance to producers in exchange for voluntarily taking marginal and environmentally sensitive land out of production and replacing it with permanent vegetative cover (Farm Service Agency 2007).

Many factors could contribute to the lack of data regarding pollinator presence in this portion of the United States. The United States Census Bureau (1991) reported that only 4.2% of the land in Texas is in public ownership, which makes access for sampling difficult. Additionally, this landscape is currently one of the most intensively cultivated regions in the Western Hemisphere (Bolen et al. 1989). Johnson et al. (2012) determined that row crops constitute almost 52% of the land base in the SHP.

One study examined if the addition of honeybees to cotton fields would be a cost effective method for hybrid cottonseed production in the Texas High Plains (Berger et al.

1985). To determine if native pollinators were providing effective more and cheaper pollination service than honeybees to these cotton fields, Berger et al. (1985) surveyed the abundance and seasonal distribution of wild bees in 1980 and 1981. *Agapostemon* spp. were most prominent, including *A. angelicus*, *A. cockerelli*, *A. coloradinus*, *A. mellinventris*, *A. texanus* and *A. splendens*. Within this genus, *A. angelilcus* comprised 98% of the samples (Berger et al. 1985). Less abundant bees included *Diadasia* spp., *Melissodes* spp., and *Perdita* spp. (Berger et al. 1985). Berger et al. (1985) did not present information on the breadth of pollinators outside of hymenopteran listed above.

Another study reviewed Texas entomological collections and electronic databases from natural history museums to confirm the historical distribution of *Bombus* spp. in Texas (Warriner 2012). Through these records, Warriner (2012) confirmed the historical presence of seven species; *B.*(*Bombias*) *auricomus*, *B*. (*Thoracobombus*) *fervidus*, *B*. (*Cullumanobombus*) *fraternus*, *B*. (*Cullumanobombus*) *griseocollis*, *B*. (*Thoracobombus*) *pensylvanicus, B*. (*Thoracobombus*) *sonorus*, and *B*. (*Psithyrus) variabilis* originally documented by Franklin (1913). Warriner (2012) documented another species in addition to those found by Franklin, *B*. (*Bombias*) *nevadensis*.

The definition of an invertebrate pollinator varies according to climate and habitat (Willmer 2011a). Most are members of 4 insect orders: Hymenoptera (ants, bees, wasps), Coleoptera (beetles), Diptera (flies), and Lepidoptera (butterflies and moths) (Proctor 1996, Council 2007, Willmer 2011a). In some habitats in North America, thrips (Order Thysanoptera) may serve as pollinators for some plant species (Council 2007). However, their recognized role as a plant pest usually supersedes their potential role as a pollinator

in many ecosystems (Council 2007). For this study, we focused on insects within the four orders above.

## MATERIALS AND METHODS

### *Study Area*

The nine SHP counties targeted in this study (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock, and Swisher) (Figure II.1) encompass approximately 2,353,522 ha. The climate is dry steppe (Smith 2003). The long-term Palmer Drought Severity Index for the region during the first week of sampling in 2013 (30 March 2013) was moderate drought, and by the last week of sampling (28 September 2013), it increased to severe drought (Climate Prediction Center Intenet Climate Prediction Center Internet Team 2016). The severe drought rating continued for the first week of sampling in 2014 (29 March 2014), and by the final week of the sampling season (27 September 2014) conditions were near normal (Climate Prediction Center Internet Climate Prediction Center Internet Team 2016). We obtained weather data from three Department of Energy weather stations within the sampling area (Amarillo, Muleshoe, and Plainview). The mean monthly temperature range for 2013 between April and September was 12.6°C – 25.9°C. The minimum monthly temperature range was 2.6°C – 18.5°C with a maximum range of 22.5°C – 33.8°C and average monthly precipitation of 0.5 mm – 77.7 mm for April through September. For 2014 between April and September, the mean monthly temperature range was 14.3°C – 25.6°C. The minimum monthly temperature range was 4.6°C – 18.9°C with a maximum range of 24°C – 33.4°C and average monthly precipitation of 13.7 mm– 129.8 mm for April through September (Menne et al. 2016b). Precipitation comes primarily from thunderstorms in May–June, and it can be highly

variable and localized (Smith 2003). In 2014, producers in the nine-county study area planted 809,978 ha with cotton, winter wheat, corn, sorghum, or soybeans (National Agricultural Statistics Service 2016) and cattle grazed most uncultivated areas (Smith and Haukos, 2002). In 2014, 292,564 ha in the study area were under CRP contract with over $ 25,624,627 in rental payments for the fiscal year (Farm Service Agency 2017). Data for 2013 were similar (Farm Service Agency 2017).

*Field Methods*

We collected insects from April through September in 2013 and 2014. In each county, we established a sampling site for each of the three dominant land uses, cropland, CRP, and native grassland. Cropland sites were the most variable of all sampling sites, with seven of the nine sites either fenced from the crop or buffered from the crop with an undisturbed or uncultivated strip of land. Crops included cotton, wheat, sorghum and corn (Chapter IV). CRP sites were composed mostly of native and introduced grasses, native and invasive flowering forbs (Chapter IV). Native grassland sites were native shortgrass prairie that never plowed but all actively grazed by cattle (Chapter IV). At each sampling site, we established six pairs of parallel transect belts, 25 m long by 2 m wide, separated by 10 m. We placed three pairs in the upland and three pairs in the playa wetland embedded within each sampling site. We divided each playa into three sections from the center and based on a random azimuth bearing; we located one transect set in each section of the playa. Upland transect sets were positioned similarly, starting within at least 25 m of the playa edge. We sampled each county once every two weeks to attempt to collect data under similar weather conditions. Bi-weekly rotation of sampling

sites over 26 weeks was to capture weather differences and ephemeral blooming periods for plants over the sampling season and to encompass life histories of invertebrates.

We collected insects with blue vane traps (Springstar™, Woodinville, Washington) and insect nets. Blue vane traps are 15 cm diameter x 15 cm tall fluorescent yellow containers with a blue polypropylene screw funnel with two 4 x 13 cm semitransparent blue polypropylene cross vanes 3 mm thick (Stephen and Rao 2005, Kimoto et al. 2012a, www.springstar.net). They are a visual attractant, not baited and do not contain killing agents or additives such as water and soap (Stephen and Rao 2005). At each pair of transect belts, we placed a 1.25 m wooden post at the midpoint of one transect (12.5 m) with a wire to hang one of these traps, for a total of six traps at each sampling site, three in the playa, and three uplands. We adjusted the height of the traps so they hung in line with the surrounding vegetation. Traps were set out each day and collected the following day with the goal of leaving them out as close to 24 hours as possible. *Apis mellifera* was not a target species, and proportionally, very few were captured (142 specimens), and all were released.

In addition to blue vane traps, we collected invertebrates with 30.5 cm insect nets as they fed on flowers. The purpose of selective sampling is to link potential pollinators with the specific plants they visit. In the transects parallel to the one with the blue vane traps, pollinators were collected separately and paired in our database with a specimen of the plant they visited (collected off-transect). Field technicians moved slowly up each transect and observed it for six minutes, "hunting" for foraging insects, targeting forb patches, and collecting insects as they visited specific plants.

*Insect Identification*

We identified insects to species as expertise and resources allowed. If that was not possible, we identified to the lowest taxonomic unit feasible. We confirmed authorities by Page RDM 2013. For Hymenoptera, keys and resources used were: Argidae (Goulet and Huber 1993, Mason 1993), all genera of bees (Michener et al. 1994), Jack Neff and Sam O'Dell (USGS NPRWC) determined *Calliopsis* species, *Habropoda* species, *Melecta* species, and *Megachile* species, Jack Neff determined *Andrena* species, *Anthophorula* species, *Triepeoles* species, *Ceratina* species, *Colletes* species, *Lasioglossum* species, *Osmia* species, *Anthidium* species and *Coelioxys* species, Sam O'Dell determined *Panurginus* species, *Holcopasites* species, *Nomia* species, and *Hoplitis* species, *Protandrena* subgenera determined by Sam O'Dell and (Michener 2007), *Perdita* subgenera (Michener 2007), *Anthophora* species (Cresson 1868), *Bombus* species (Ascher and Pickering 2016e), *Centris* species determined by Jack Neff and (Snelling 1974, Roberts 2007), *Diadasia* species (Timberlake 1941), *Melitoma* species (Ascher and Pickering 2016m), *Ericrocis* species (Ascher and Pickering 2016j), *Eucera* species determined by Jack Neff and (Timberlake 1969), *Melissodes* species determined by Karen Wright and (LaBerge 1956a, 1956b, 1961, Ascher 2016a, Ascher 2016b ), *Peponapis* species (Ayala and Griswold 2012), *Svastra* species determined by Jack Neff and (LaBerge 1958), *Tetraloniella* (LaBerge 2001), *Xenoglossa* species (Ascher and Pickering 2016n), *Anthophorula* subgenus (Michener 2007), *Xeromelecta* species (Ascher and Pickering 2016o), *Epeolus* species (Ascher and Pickering 2016h, 2016i), *Xylocopa* species (Ascher and Pickering 2016p), *Dieunomia* species (Ascher and Pickering 2016g), *Augochlora*, *Augochlorella*, and *Augochloropsis* species (Sandhouse 1937), *Agapostemon* (Ascher and Pickering 2016b), *Halictus* (Ascher and Pickering

2016k), *Lasioglossum* subgenera (Michener 2007), *Lithurgus* and *Lithurgopsis* species (Ascher and Pickering 2016l), *Ashmeadiella* species determined by Sam O'Dell and (Ascher and Pickering 2016d), *Anthidium* species determined by Jack Neff, Sam O'Dell, and (Ascher and Pickering 2016c), *Dianthidium* species determined by Jack Neff, Sam O'Dell, and (Ascher and Pickering 2016f), *Megachile* subgenera (Michener 2007), Astatidae, Bethylidae, Braconidae, Cheloninae, Chalcidoidae, Chalcididae, Chrysididae, Chrysidinae, Crabronidae, Bembicinae, Crabroninae, Larrinae, Philanthidae, Philanthinae, Cynipidae, Formicidae, Ichneumonidae, Multillidae, Sphaerophalminae, Nyssonidae, Perilampidae, Philanthridae, Philanthinae, Platygastridae, Pompilidae, Pepsinae, Pompilinae, Scoliidae, Scoliinae, Sphecidae, Ammophilinae, Sceliphrinae, Sphecinae, Tiphiidae, Brachycistidinae, Typhinae, Methochinae, Myzininae, Torymidae, Vespidae, and Eumeninae (Goulet and Huber 1993, Mason 1993), *Bembix* species (Bohart and Horning 1971), tribes, genera and species of Philanthinae (Bohart and Grissell 1975), genera of Scollinae (MacKay 1987), genera of Myzininae (Krombein 1937), genera of Eumeninae (Carpenter 2004a), genera of Polistinae (Carpenter 2004b), and *Polistes* species determined by Hal Reed. Wasp group names and classification were confirmed by (Pulawski 2014). For Coleoptera, all families were determined using Triplehorn and Johnson (2005) and Ivie (2000). We keyed several families of Coleoptera to subfamily, tribe, genus and/or species; Buprestidae (Bellamy and Nelson 2002), Cantharidae (Fender 1964), Carabidae (Ball and Bousquet 2001), Cerambycidae (Turnbow and Thomas 2002), Chrysomelidae (Riley et al. 2002), Cleridae (Barr 1962, Opitz 2002), Hydrophilidae (Van Tassel 2001), Lampyridae (Lloyd 2002), Meloidae (Enns 1956, Arnold 1976, Selander 1982), Melyridae (Mayor 2002), Nitidulidae (Habeck

2002), Scarabaeidae (Ratcliff et al. 2002), Staphylinidae (Newton et al. 2001) and Tenebrionidae (Aalbu et al. 2002). For Diptera, families were determined using McAlpine (1981) and Triplehorn and Johnson (2005). We keyed several families of Diptera to subfamily, tribe, genus and/or species; Anthomyiidae (Huckett 1987), Asilidae (Wood 1981), Bombyliidae (Hall 1981), Calliphoridae (Whitworth 2006), Chloropidae (Sabrosky 1987), Conopidae (Smith and Peterson 1987), Muscidae (Huckett and Vockeroth 1987), *Mythicomyia* sp. determined by Sam O'Dell, Sarcophagidae (Shewell 1987), Stratiomyidae (James 1981), Syprhidae (Vockeroth and Thompson 1987, Miranda et al. 2013), Tabanidae (Pechuman and Teskey 1981), Tachinidae (Wood 1987) and Tephritidae (Foote and Steyskal 1987).

Many of our Lepidoptera specimens were damaged because of severe weather (rain and wind) during several of the sampling periods or because of damage while in the trap. The specimens captured with insect nets were in better condition. We determined butterflies with field guides (Dole et al. 2004, Eaton and Kaufman 2007) and moths by photographs from the North American Moth Photographers Group (North American Moth Photographers Group 2011).

Before identification, insects were stored frozen to -20 C. We pinned species used for our reference collection. The Oklahoma State University K.C. Emerson Entomology Museum in Stillwater OK houses the bulk of the pinned insect specimens from the study, and the sweep net samples are at the USGS NPWRC in Jamestown, ND.

*Statistical Analysis*

We performed statistical analysis with R 3.3.2. (R Core Development Team 2016). We compared frequency of insect abundance by order between capture methods

(vane trap or insect net) using Pearson's Chi-squared Test to determine if both methods of capture were necessary to adequately capture richness when sampling pollinator communities.

## RESULTS

We collected 74,358 insects in the study area in 2013 and 2014 (Tables II.1 – 5). We collected 72,776 specimens with blue vane traps and 1,581 specimens through targeted hunting with sweep nets.

For both capture methods combined, Hymenoptera comprised the largest portion of insects sampled (63.0%) (Figure II. 2). Hymenoptera capture included six bee families and 59 identified genera, 20 wasp families and 29 genera, and Formicidae and Argidae. Wasps were a minor portion of the specimens collected (Figure II.3). Within Hymenoptera, the family Apidae consisted of the majority of specimens collected followed by Halictidae (Figure II.4). Within Apidae, *Melissodes* spp. (62.7%) and *Diadasia* spp. (20.3%) comprised the majority of the family (Figure II.5). Within Halictidae, *Lasioglossum* spp. (47.2%) and *Agapostemon* spp. (45.6%) were the majority of the family (Figure II.6). We were unable to identify six specimens of Hymenoptera past order because they were damaged.

Coleoptera was the next largest portion of specimens collected, with 28.6% of the total specimens represented by 33 families and 67 genera. The five most abundant families are Meloidae, Cantharidae, Nitidulidae, Anthicidae, and Buprestidae (Figure II.7). Six genera represented Meloidae and were the majority of beetles. Twenty-one Coleoptera specimens were too damaged to identify beyond order.

Diptera comprised only 4.5% of the specimens but included 40 families and 65 genera. Syrphidae and Bombyliidae, the two most important pollinator families (Kevan and Baker 1983, Proctor 1996, Wilmer 2011c, Abrol 2012), were the most abundant (Figure 8).We could not identify 120 specimens beyond order because they were too small or damaged.

Lepidoptera represented the smallest portion of the samples with 17 families and 32 genera. Noctuidae comprised just over half of the order (54.2%). Because they were in poor condition from vane traps, we could not identify many specimens beyond order (12.3%, 215 specimens).

There was a frequency difference between capture method with all orders [$\chi 2(4, N = 74,358) = 1,649.6, p < 0.0001$] (Table II.6). Blue vane traps captured a higher frequency of Hymenoptera than sweep nets [$\chi 2(1, N = 46,846) = 678.1, p < 0.0001$], a lower frequency of Coleoptera than sweep nets [$\chi 2(1, N = 21,235) = 72.218, p < 0.0001$], a lower frequency of Diptera than sweep nets [$\chi 2(1, N = 3,322) = 1,119.1, p < 0.0001$], a lower frequency of Lepidoptera than sweep nets [$\chi 2(1, N = 1,754) = 254.33, p < 0.0001$], and a higher frequency of insects in the remaining combined orders [$\chi 2(1, N = 1,200) = 23.473, p < 0.0001$] (Table II.6).

DISCUSSION

*Hymenoptera*

Warriner (2012) found *Bombus fraternus* in Floyd and Lubbock Counties, and *B. pensylvanicus* in Hockley and Lubbock Counties. We did not capture *B. fraternus*; however, we did find *B. pensylvanicus* in all counties sampled (Bailey, Briscoe, Carson, Castro, Hockley, Gray, Lubbock, and Swisher counties). We collected 376 *Bombus* sp.

(1.18% of Apidae collected) and determined that 352 of those were *B. pensylvanicus*. We could not identify four past *Bombus* sp. We were not able to differentiate 20 specimens from *B. sonorus,* which is closely related to *B. pensylvanicus* (Ascher and Pickering 2016e). The IUCN status of *B. pensylvanicus* is "Vulnerable" (Hatfield et al. 2015). Berger et al. (1985) found several species of *Agapostemon* including *A. angelicus*, *A. cockerelli*, *A. coloradinus*, *A. mellinventris* Cresson, *A. texanus* and *A. splendens*. According to the *Agapostemon* key provided in Discoverlife.org (Ascher and Pickering 2016b), *A. angelicus* and *A. texanus* ranges overlap in our sampling area, and females of each species are difficult to differentiate using external morphology. We found *Agapostemon* specimens in all counties sampled and we designated them as *A. angelicus* or *A.texanus* in our species list. We separated males by species and found both species in all counties. The remaining *Agapostemon* species, *A. coloradinus* (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock), *A. melliventris* (Bailey, Carson, Floyd, Gray, Hockley, Lubbock), and *A. splendens* (Bailey, Carson, Gray, Hockley, Lubbock) were not as abundant. We did not find *Agapostemon cockerelli*. Berger et al. (1985) also identified *Diadasia* spp., *Melissodes* spp., and *Perdita* spp.in their study. Each of these genera was present in all of the counties we sampled, and *Melissodes* spp. and *Diadasia* spp. were the two most abundant genera in Apidae. *Perdita* spp. was the most abundant genus in Andrenidae.

The percentage of Hymenoptera, specifically bees, captured by sweep nets was lower than with blue vane traps (Table II.6). Blue vane traps were left out for 24 hours to trap a variety of bees feeding at different times during the day (including nocturnal or crepuscular) and during a more extensive variety of weather conditions, whereas sweep

netting was limited temporally to within 1 hour during the day. There is evidence that blue vane traps are powerful attractants and can attract bees even with a dearth of floral resources. For example, in certain conditions, these traps can divert bees from floral resources, collecting more species and individuals than other capture methods (Stephen and Rao 2007). Additionally, bees can move quickly and can be difficult to capture with nets depending upon their foraging behavior. The blue vane traps were the most effective method of capturing bees in our study. Past research has shown similar results with these traps (Stephen and Rao 2005, 2007, Kimoto et al. 2012a, Joshi et al. 2015). Capture with insect nets did result in the collection of one genus of bee (three specimens) not represented in the vane traps, *Panurginus* sp., and one species of wasp, *Astata* sp. (one specimen) (Table 1).

We considered all bees collected as pollinators, and all other invertebrates as potential pollinators or anthophiles (Kevan and Baker 1983, Proctor 1996, Wilmer 2011d, Abrol 2012).

*Coleoptera*

The percentage of Coleoptera captured by blue vane traps was lower than with insect nets (Table II.6). Insect nets can be biased toward larger, slower insects that are easier to capture and result in higher collection rates (Zou et al. 2012). Additionally, many Coleoptera, especially those in Cantharidae and Meloidae, tended to feed in large clumps on flowers at our collection sites, so it was easy to capture many at once with less effort in a shorter amount of time. These were the two most frequent genera in the study (Figure II.7).

Coleopterans are considered primitive pollinators (Kevan and Baker 1983, Bernhardt 2000, Wilmer 2011b), and although they serve as keystone pollinators in tropical and arid ecosystems, their overall importance to pollination service might be underestimated in other ecosystems (Bernhardt 2000). Although many beetles are generalists and sometimes-accidental pollinators, many are also destructive and can cause economic damage in addition to incidental pollination (Kevan and Baker 1983, Proctor 1996, Wilmer 2011b, Abrol 2012). The most important beetle family in our specimens that potentially serves as a pollinator belonged to Cantharidae, genus *Chauliognathus* spp., commonly known as soldier beetles. Several studies have shown that *Chauliognathus* spp. can be significant pollinators of some flowers such as *Nelumbo lutea* (Bernhardt 2000) and *Solidago* spp. (Gross and Werner 1983, Buchele et al. 1992, Graham et al. 2012). Meloidae, especially *Epicauta* spp. (blister beetles) are considered pests and can cause extensive agricultural damage and death to horses when accidentally consumed. However, studies have shown that even though some meloids can be damaging to leaves and many portions of the flower, in some plants they leave the ovary undamaged and do not prevent pollination (Bernhardt 2000). Chrysomelidae might also play a role as minor pollinators; however, many species in this genus also skeletonize plant leaves and flowers (Triplehorn and Johnson 2005, Wilmer 2011b). Carabidae and Scarabaeidae are potential pollinators (Kevan and Baker 1983, Proctor 1996, Wilmer 2011b, Abrol 2012), but outside of tropical and arid ecosystems, they are usually considered destructive to crops (Kevan and Baker 1983). These families only comprised a small portion of our samples. The following families that are represented in our samples based on their behavior, habitat, and feeding habits are unlikely to serve as pollinators in

our sampling area: Anobiidae, Anthribidae, Attelabidae, Dytiscidae, Hydraenidae, Hydrophilidae, Lampyridae, Ochodaeidae, Mycetophagidae, Tenebrionidae, and Throscidae (Triplehorn and Johnson 2005). These specimens were collected in small numbers and may have been accidental capture (Table II.2).

*Diptera*

The percentage of Diptera captured by blue vane traps was lower than with insect nets (Table II.6) with insect nets obtaining a larger percentage of flies (21.7%) than the vane traps (4.1%). The disparity of capture might be because the traps could not contain the flies once they entered the trap, or flies may not be as attracted to traps as they are to specific flowers.

Dipterans, like coleopterans, are considered primitive pollinators, (Kevan and Baker 1983) and many feed on nectar (Triplehorn and Johnson 2005). Others feed on pollen and floral tissue (Larson et al. 2001) and in the process, may serve as accidental pollinators. Although their role as pollinators is often overlooked, mostly due to the assumption that they are unimportant and difficult to identify (Orford et al. 2015), they are the second most important pollinator order behind bees (Larson et al. 2001). In instances where their ability to move significant amounts of pollen between plants may be marginal, their sheer abundance can compensate (Saeed et al. 2008, Orford et al. 2015).

The most significant dipteran pollinator family is Syrphidae followed by Bombyliidae, Muscidae, Tachinidae, Conopidae, and Calliphoridae. Both capture methods combined yielded the highest percentage of two of the primary Diptera pollinator families, Bombyliidae and Syrphidae (Figure II.8). Specimens from the other

families were captured in lower numbers. Sweep netting captured several genera of Bombyliidae flies not captured in the vane traps; *Chrysanthrax* sp., *Lepidantrax* sp., *Paravilla* sp., and *Villa* sp., two species of Syrphidae; *Palpada vinetorum* and *Syritta flaviventris*; and a genus of Mythicomyiidae, *Mythicomyia* sp. Most of the dipteran families captured are potentially anthophilous, but we excluded Ulidiidae, Sphaeroceridae, Clusiidae, and Tanypezidae because described behavior did not include floral visitation (Triplehorn and Johnson 2005).

*Lepidoptera*

Lepidoptera comprised the smallest percentage of our specimens, and many were in such poor condition following capture that they were difficult to identify past family. Members of Noctuidae were the largest portion of our Lepidoptera specimens (54.2%), and many genera are considered agricultural pests. Four species of potential pollinators were captured by sweep nets and not found in blue vane traps: *Pontia protodice*, *Nathalis iole*, *Echinargus isola*, and *Brephidium exilis*.

Included in Table II.5 is a list of specimens from other orders. Although these have the potential to serve the role as pollinators (Kevan and Baker 1983, Larson et al. 2001, Wilmer 2011b), we considered them anthophiles.

*Conclusion*

Based on a review of the current literature, this is the most comprehensive list of pollinators and athophiles in the SHP region of Texas. Most studies of this type only include melittofauna, but we have included other Hymenoptera such as wasps and sawflies with 289 taxa, 150 taxa of coleopterans, 115 taxa of dipterans, 60 taxa of lepidopterans, and 15 taxa from other orders that might be anthophiles in this landscape.

Richness is likely much higher because we only keyed many taxa to family, subfamily or tribe. Our Hymenoptera capture results were similar to other studies using blue vane traps in that *Melissodes* spp. were the most abundant bee collected (Stephen and Rao 2005, Kimoto et al. 2012a, Geroff et al. 2014), and *Lasioglossum* spp. were also abundant (Kimoto et al. 2012a). Blue vane traps are also highly effective in capturing *Bombus* spp. (Stephen and Rao 2005, Kimoto et al. 2012a, Geroff et al. 2014). Our *Bombus* spp. capture numbers were low (1.18% of Apidae), but given the success of past studies, it is likely because the SHP is not rich or abundant in *Bombus* species. Although many studies support that including a variety of trapping methods in sampling protocol may allow a more accurate representation of the landscape assemblage of bees, Stephen and Rao (2005) determined that for bee surveys, blue vane traps might serve as an effective alternative to multiple trapping methods. Addition of sweep netting in our study only added one bee genus (3 specimens) and one wasp species (1 specimen) to our Hymenoptera taxa list. There have not been studies to determine the effectiveness of blue vane traps in collecting dipterans or coleopterans. Sweep netting did not increase richness for coleopterans, but it did add four genera of Bombyliidae, two species of Syrphidae, and four species of lepidopterans to our taxa list. Greater Diptera capture could be due to trapping bias, or possibly, because many fly specimens were damaged in the blue vane traps, which made identification of genus or species difficult, and we may have only identified these taxa to family with vane trap specimens.

There were no studies within the region to compare richness, so we referenced studies from a semi-arid prairie in Oregon and the Northern Great Plains in South Dakota. Kimoto et al. (2012a) collected bees in 2007-2008 with blue vane traps in the

Zumwalt high altitude bunchgrass prairie in northeast Oregon. They found 94 species and 117 morphospecies of wild bees on sixteen 40 ha study plots. In the Brookings, SD, a survey of the USDA-ARS North Central Agricultural Research Laboratory research farm identified 114 pollinator species (Mogren et al. 2016). In the nine-county study area of the SHP from 2013-2014, we collected 127 species of wild bees representing 58 genera, similar to other bunch grass and shortgrass prairies. This study documents pollinator, potential pollinator, and anthophile species present in a highly altered landscape. It is the most comprehensive list of pollinators and anthophiles in this region to date and is important for establishing baseline data for documentation of the status of pollinators in this region.

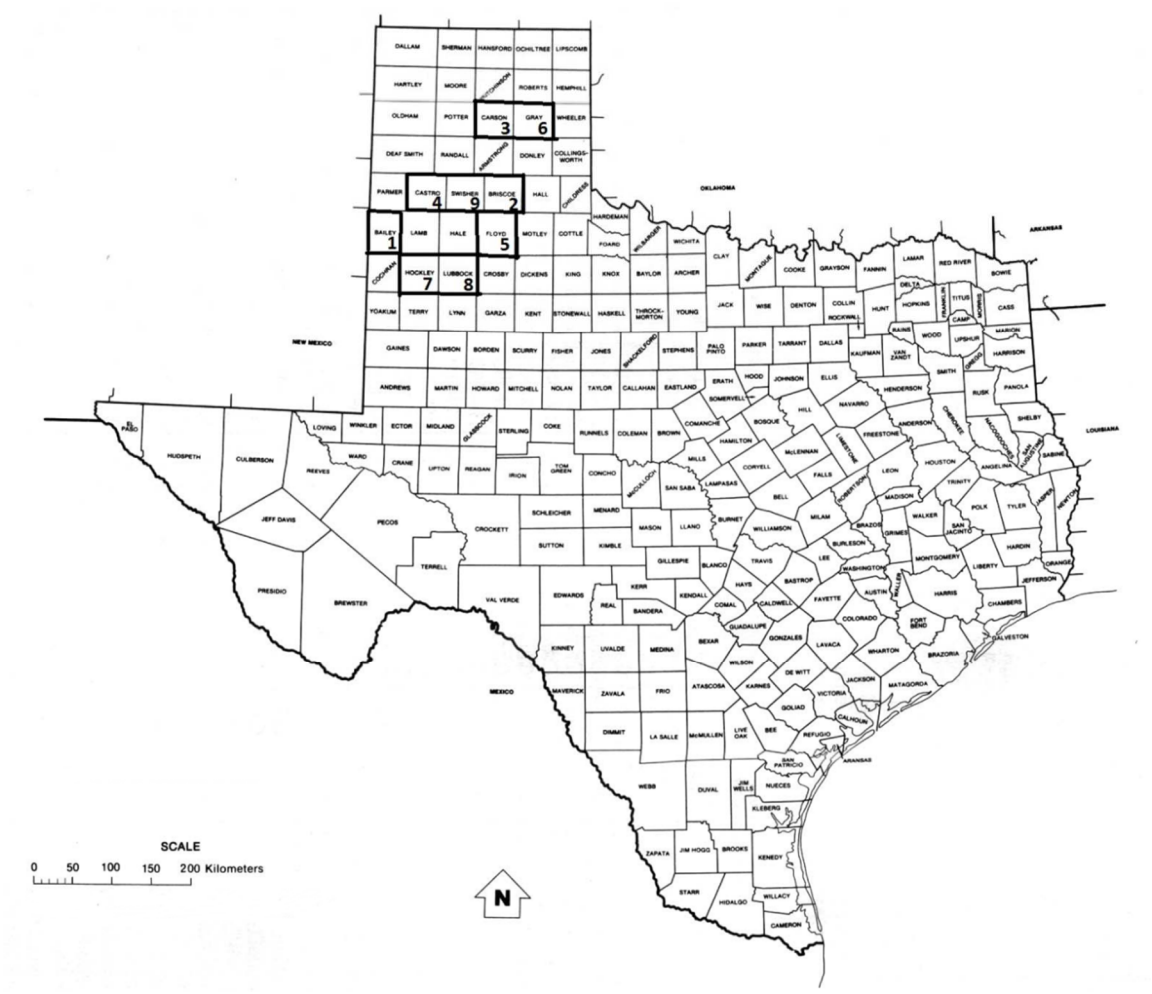


Figure II.1. Counties in the Southern High Plains of Texas where pollinator sampling took place in 2013–2014. 1= Bailey Co., 2 = Briscoe Co., 3 = Carson Co., 4 = Castro Co., 5 = Floyd Co., 6 = Gray Co., 7 = Hockley Co., 8 = Lubbock Co., 9 = Swisher Co. Map courtesy of the University of Texas Libraries, The University of Texas at Austin.

Table II.1. Hymenoptera captured in the Southern High Plains of Texas in 2013–2014. Sex collected is indicated when possible; N = number of specimens; v = blue vane capture; n = insect net capture; ba = Bailey County, br = Briscoe County, car = Carson County, cas = Castro County, fl = Floyd County, gr = Gray County, ho = Hockley County, lu = Lubbock County, sw = Swisher County

| Hymenoptera taxa | N | Sex | Capture Method | County |
|---|---|---|---|---|
| HYMENOPTERA | 6 | | v | ba, br,cas, gr, ho, lu |
| SYMPHYTA | | | | |
| TENTHREDINOIDEA | | | | |
| ARGIDAE Thiele | 44 | | n,v | ba, br, car, cas, gr, ho, lu, sw |
| *Zynzus* sp. Smith | 15 | | v | ba, cas, gr, sw |
| APOCRITA | | | | |
| ICHNEUMONOIDEA | | | | |
| BRACONIDAE Mantero | 164 | | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| CHELONINAE | 2 | | n | |
| *Chelonus* sp. Braet | 9 | | v | ba, br, car, gr |
| ICHNEUMONIDAE Lucas | 48 | | n,v | ba, br, cas, fl, gr, ho, lu, sw |
| CHALCIDOIDEA | 2 | | v | cas, ho |
| TORYMIDAE | 6 | | n,v | ba, ho |
| APOIDEA | 1 | | v | sw |
| PERILAMPIDAE | 86 | | v | ba, br, cas, gr, ho |
| CHALCIDIDAE Dalla Torre | 17 | | v | ba, cas, fl, gr, ho, lu |
| CYNIPOIDEA | | | | |
| CYNIPIDAE | 22 | | v | ba, cas, ho, lu |
| PLATYGASTROIDEA | | | | |
| PLATYGASTRIDAE Haliday | 1 | | v | ho |
| CHRYSIDOIDEA | | | | |
| CHRYSIDIDAE | 31 | | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| CHRYSIDINAE Latreille | 6 | | v | br, car, fl |
| Chrysidini | | | | |
| *Caenochrysis* sp. Kimsey and Bohart | 4 | | v | gr |
| *Caenochrysis carinata* (Say) | 1 | | v | lu |
| *Ceratochrysis* sp. Cooper | 3 | | v | car, fl |
| *Chrysis* sp. | 4 | | v | fl, ho, lu |
| *Chrysura* sp. Dahlbom | 2 | | v | cas, sw |
| BETHYLIDAE | 7 | | v | ba, br, cas, sw |
| ANDRENIDAE Latrelle | 2 | | v | br, sw |
| ANDRENINAE Latrelle | | | | |
| *Ancylandrena* sp. Cockerell | 1 | m | v | car |

| | | | | |
|---|---|---|---|---|
| Andrenini | | | | |
| *Andrena spp.* F. | 64 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *A. (Callandrena) accepta* Viereck | 2 | f,m | v | ba, lu |
| *A. (Melandrena) brevicornus* Bouseman and LaBerge | 1 | f | v | ba |
| *A. (Plastandrena) prunorum* Cockerell | 2 | f | v | br |
| *A. (Rhaphandrena) dapsilis* LaBerge | 1 | f | v | ho |
| *A. (Rhaphandrena) prima* Casad | 5 | f,m | v | cas, gr, ho |
| PANURGINAE Leach | | | | |
| Calliopsini Robertson | | | | |
| *Calliopsis* spp. Smith | 15 | f,m | v | ba, br, car, cas, sw |
| *C.(Calliopsima) coloradensis* Cresson | 1 | | n | fl |
| *C.(Calliopsima) rozeni* Shinn | 1 | m | v | fl |
| *C. (Verenapis) verbenae* Cockerell | 1 | | v | ho |
| Panurgini Leach | | | | |
| *Panurginus* sp. Nylander | 1 | | n | car |
| *P. beardsleyi* (Cockerell) | 2 | | n | car |
| Perditini Robertson | | | | |
| *Perdita* spp. Smith | 325 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *P. (Cockerellia)* | 146 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *P. (Cockerellia) perpulchra* Cockerell | 25 | f,m | v | ba, br, car, fl, gr, ho, lu |
| *P. (Hexaperdita)* | 261 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu |
| *P. (Perdita)* | 23 | f,m | n,v | car, gr, ho, lu |
| Protandrenini Robertson | | | | |
| *Protandrena* sp. Cockerell | 9 | f,m | v | cas, fl, gr, lu, sw |
| *P.cockerellli Dunning* | 1 | f | v | fl |
| *P. (Metapsaenythia)* Timberlake | 1 | m | v | gr |
| *P. (Heterosarus)* | 13 | f | n,v | br, fl, lu, sw |
| *P.(Protandrena* s.str*)* | 1 | | n | ho |
| *P.(Pterosarus)* | 2 | | n,v | br, fl, |
| *Pseudopanurgus* spp. Cockerell | 8 | f | v | ba, fl, ho |
| APIDAE Latreille | 7 | | v | br, cas, fl, gr |
| APINAE Latreille | | | | |
| Anthophorini Dahlbom | | | | |
| *Anthophora* sp. Latreille | 51 | f,m | v | ba, br, car, cas, fl, gr,ho, lu, sw |
| *A. (Anthophoroides) californica* Cresson | 84 | f,m | v | ba, br, car, cas, fl, ho, lu, sw |

| | | | | |
|---|---|---|---|---|
| *A.(Anthophoroides) vallorum* (Cockerell) | 2 | f | v | lu |
| *A.(Lophanthophora) affablis* Cresson | 683 | f,m | v | ba, br, car, cas, fl, gr,ho, lu, sw |
| *A.(Lophanthophora) fedorica* Cockerell | 1 | f | v | car |
| *A.(Melea) bomboides* Kirby | 13 | f | v | br, car, cas, gr, sw |
| *A.(Melea) occidentalis* Cresson | 158 | f,m | v | ba, br, car, fl, gr, ho, lu, sw |
| *A. (Mystacanthophora)montana* Cresson | 313 | f,m | v | ba, br, car, cas, fl, gr,ho, lu, sw |
| *A.(Mystacanthophora) urbana* Cresson | 4 | f | v | br, fl, sw |
| *A.(Mystacanthophora) walshii* Cresson | 134 | f,m | v | ba, br, car, cas, fl, gr,ho, lu, sw |
| *Habropoda* sp. (F.) | 11 | f,m | v | ba, br, car, fl, ho, lu, sw |
| *H. morrisoni* (Cresson) | 6 | f | v | ba, fl, gr |
| *H. vierecki* (Cockerell) | 6 | f,m | v | ba, br, fl, ho |
| Apini Latreille | | | | |
| *Apis (Apis) mellifera* L. | 142 | f | n,v | ba, br, car, fl, gr, ho, lu, sw |
| Bombini Latreille | | | | |
| *Bombus* sp. Latreille | 4 | f | v | gr, sw |
| *B.(Thoracobombus) pensylvanicus* (DeGeer) | 352 | f,m | n,v | ba, br, car, fl, gr, ho, lu, sw |
| *B. pensylvanicus/sonarus* | 20 | f,m | v | br, car, fl, gr, lu, sw |
| Centridini Cockerell and Cockerell | | | | |
| *Centris* sp. F. | 3 | f,m | v | ba, car, fl |
| *C.(Paracentris) atripes* Mocsary | 5 | f,m | v | ba, br, ho |
| *C.(Paracentris) caesalpinae* Cockerell | 9 | f | v | ba, cas, ho, lu |
| *C.(Paracentris) cockerelli* Fox | 5 | f,m | v | car, cas, fl, gr |
| *C.(Paracentris) lanosa* Cresson | 498 | f,m | v | ba, br, car,fl, gr, ho, lu, sw |
| Emphorini Robertson | | | | |
| *Ancyloscelis* sp. Latreille | 5 | f | n,v | cas, gr |
| *Ancyloscelis sejunctus* Cockerell | 1 | | n | ho |
| *Diadasia* spp. Patton | 431 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *D.(Coquillettapis) australis* (Cresson) | 30 | f,m | v | ba, br, car, fl, ho, lu, sw |
| *D.(Coquillettapis) diminuta* (Cresson) | 205 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *D.(Diadasia) enavata* (Cresson) | 2501 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *D.(Coquillettapis) piercei* | 13 | f,m | v | fl, lu, sw |

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|---|---|---|---|---|
| Cockerell | | | | |
| *D.(Coquillettapis) rinconis* Cockerell | 3209 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *D.(Dasiapis) ochracea* (Cockerell) | 61 | f,m | n,v | ba, br, fl, gr, ho, lu |
| *Melitoma* sp. (Say) | 4 | f | v | fl, gr |
| *M. grisella* (Cockerell and Porter) | 1 | f | v | gr |
| Ericrocidini Cockerell and Atkins | | | | |
| *Ericrocis* sp. (Cresson) | 12 | f,m | v | ba, br, cas, lu, sw |
| *E. lata* (Cresson) | 23 | f,m | v | br, car, fl, gr, lu, sw |
| Eucerini Latreille | 2 | | v | gr |
| *Eucera* sp. Scopoli | 172 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *E. (Synhalonia) conformis* (Cresson) | 1 | f | v | lu |
| *E.(Synhalonia) dubitata* (Cresson) | 48 | f,m | v | ba, br, car, cas, fl, gr, ho, lu |
| *E.(Synhalonia) hamata* (Bradley) | 33 | f,m | v | ba, car, gr, lu, sw |
| *E.(Synhalonia) lepida* (Cresson) | 12 | f,m | v | br, car, cas, |
| *E. (Synhalonia) pallidihirta* (Timberlake) | 1 | f | v | br |
| *E.(Synhalonia) speciosa* (Cresson) | 73 | f,m | v | ba, br, car, fl, gr, ho, lu |
| *Florilegus (Florilegus) condignus* (Cresson) | 149 | f,m | v | ba, br, car, cas, fl, lu, sw |
| *Melissodes* sp. Latreille | 1277 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Callimelissodes)* | 6 | f,m | v | fl |
| *M. (Callimelissodes) tuckeri* Cockerell | 5 | f,m | v | car, fl |
| *M. (Eumelissodes)* | 39 | f,m | v | br, cas, gr, sw |
| *M. (Eumselissodes) agilis* Cresson | 1890 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Eumelissodes) coreopsis* Robertson | 3844 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Eumelissodes) menuachus* Cresson | 14 | f,m | v | ba, car, ho, lu |
| *M. (Eumelissodes) snowii* Cresson | 1 | m | v | ba |
| *M. (Eumelissodes) subagilis* Cockerell | 1 | f | v | ba |
| *M. (Eumelissodes) submenuachus* Cresson | 1 | | n | br |
| *M. (Eumelissodes) trinodis* Robertson | 15 | f,m | v | ba, fl, ho, lu |
| *M. (Eumelissodes) tristis* Cockerell | 5219 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Eumelissodes) verbesinarium* Cockerell | 2 | f | v | br |

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| *M. (Eumelissodes) vernoniae* Robertson | 130 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Heliomelissodes) rivalis* Cresson | 600 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Melissodes) communis* Cresson | 6492 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Melissodes) comptoides* Cresson | 193 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Melissodes)* | 9 | f,m | v | br, cas, sw |
| *M. (Melissodes) paroselae* Cockerell | 4 | f | v | fl, lu |
| *M. (Melissodes) tepaneca* Cresson | 36 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Melissodes) thelypodii* Cockerell | 144 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M. (Psilomelissodes) intortus* Cresson | 1 | f | v | car |
| *Melissoptila* sp. Holberg | 1 | | v | ho |
| *Peponapis* sp. (Say) | 5 | f,m | v | ba, br, gr |
| *P. (Peponapis) pruinosa* (Say) | 15 | f,m | v | fl, gr, ho lu, sw |
| *Svastra* spp. Holmberg | 233 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *S. (Brachymelissodes) cressonii* (Dalla Torre) | 73 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *S. (Epimelissodes) atripes* (Cresson) | 127 | f,m | v | ba, br, car, cas, fl, gr, lu, sw |
| *S.(Epimelissodes) obliqua* (Say) | 538 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *S.(Epimelissodes) petulca* (Cresson) | 24 | f,m | v | ba, br, car, cas, fl, gr, ho, sw |
| *S.(Epimelissodes) texana* (Cresson) | 301 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Tetraloniella* spp. Ashmead | 116 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *T.(Tetraloniella) eriocarpi* (Cockerell) | 4 | f | v | car, lu |
| *T. (Tetraloniella) helianthorum* (Cockerell) | 1 | f | v | ba |
| *T.(Tetraloniella) spissa* (Cresson) | 66 | f,m | n,v | br, car, fl, gr, lu |
| *Xenoglossa* spp. Smith | 133 | f,m | v | car, cas fl, gr, ho, lu, sw |
| *X.(Eoxenoglossa) kansensis* Cockerell | 9 | f,m | v | car, cas, gr, ho, lu |
| *X.(Eoxenoglossa) strenua* (Cresson) | 98 | f,m | v | ba, br, cas, fl, gr, ho, lu, sw |
| Exomalopsini Vachal | | | | |
| *Anthophorula* sp. Cockerell | 51 | f,m | v | ba, br, car, fl, gr, ho, lu, |

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|---|---|---|---|---|
| | | | | sw |
| *A. (Anthophorisca)* | 2 | | n | br |
| *A. (Anthophorula)* | 54 | f,m | n,v | ba, car, cas, gr, ho, lu |
| *A. (Anthophorula) compactula* Cockerell | 17 | f,m | v | ba, gr, ho |
| *Exomalopsis* sp. Spinola | 23 | f,m | v | ba, car, cas, fl, ho, lu, sw |
| Melectini Westwood | | | | |
| *Melecta pacifica* Cresson | 77 | f | v | ba, br, car, cas, fl, gr, ho, lu |
| *Xeromelecta* sp. Linsley | 3 | m | v | ba, fl, gr |
| *X.(Melectamorpha) interupta* (Cresson) | 1 | | v | br |
| *Zacosmia* sp. Ashmead | 3 | | v | lu |
| NOMADINAE Latreille | | | | |
| Ammobatoidini Michener | | | | |
| *Holcopasites* sp. Ashmead | 2 | f | v | br, fl |
| *H. calliopsidis* (Linsley) | 1 | | n | br, fl |
| Epeolini Robertson | | | | |
| *Epeolus* sp. Latreille | 34 | f,m | n,v | ba, car, cas, fl, gr, ho, lu, sw |
| *E. scutellaris* Say | 6 | f | v | cas, fl, ho |
| *Triepeoles* sp. Robertson | 171 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *T.* (verbesinae group) sp. Cockerell | 13 | | v | br, car, fl, gr, lu |
| Neolarrini Fox | | | | |
| *Neolarra* sp. s. str. (Crawford) | 7 | f | v | ba, ho, lu |
| Nomadini Latreille | | | | |
| *Nomada* sp. Scopoli | 102 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| XYLOCOPINAE Latreille | | | | |
| Ceratinini Latreille | | | | |
| *Ceratina* sp. Latreille | 4 | f | v | fl, ho |
| *C. (Zadontomerus) shinnersi* Daly | 3 | m | v | ho |
| Xylocopini Latreille | | | | |
| *Xylocopa (Xylocopoides) virginica* (L.) | 53 | f,m | v | br, car, fl, gr, lu, sw |
| COLLETIDAE Lepeletier | | | | |
| COLLETINAE Lepeletier | | | | |
| Colletini Lepeletier | | | | |
| *Colletes* sp. Latreille | 202 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *C.birkmanni* Swenk | 2 | f | v | fl |
| *C.salicicola* Cockerell | 1 | f | v | ho |
| HYLAEINAE Viereck | | | | |
| *Hylaeus* sp. s. str. F. | 3 | f,m | v | car, lu |
| XEROMELISSINAE Cockerell | | | | |

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| *Chilicola* sp. s. str. Spinola | 1 | f | v | ho |
| HALICTIDAE Thomson | 12 | f | v | br, cas, ho |
| ROPHITINAE Schenck | | | | |
| *Dufourea* sp. Lepeletier | 2 | f | v | gr, ho |
| *Sphecodosoma* sp. Crawford | 2 | f | v | car, ho |
| NOMIINAE Robertson | | | | |
| *Dieunomia* sp. Cockerell | 8 | f | v | gr, ho, lu |
| *D.nevadensis* (Cresson) | 1 | f | v | car |
| *Nomia* sp. Latreille | 5 | f | v | ba, cas, fl, gr, lu |
| *N.(Acunomia) foxii* Dalla Torre | 1 | m | v | fl |
| *N.(Acunomia) nortoni* Cresson | 1 | | n | ho |
| HALICTINAE Thomson | | | | |
| Augochlorini Beebe | | | | |
| *Augochlora (Augochlora) pura* (Say) | 9 | f | v | fl, lu |
| *Augochlorella* sp. Sandhouse | 5 | f | v | fl, ho, lu |
| *A. aurata* (Smith) | 24 | f,m | n,v | car, fl, gr, ho, lu |
| *Augochloropsis* sp. Cockerell | 22 | f | v | fl, gr, ho, lu |
| *A. (Paraugochloropsis) metallica* (F.) | 41 | f | n,v | br, car, fl, gr, ho, lu |
| Halictini Thomson | | | | |
| *Agapostemon (Agapostemon) angelicus* Cockerell | 555 | m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| A. angelicus/texanus | 2976 | f | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *A.(Agapostemon) coloradinus* Valchal | 115 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu |
| *A.(Agapostemon) femoratus* Crawford | 6 | f,m | v | br, car, gr, lu |
| *A.(Agapostemon) milliventris* Cresson | 90 | f,m | v | ba, car, fl, gr, ho, lu |
| *A. (Agapostemon) sericeus* (Forster) | 1 | f | v | ho |
| A. *sericeus/obliqua* | 37 | f | v | ba, br, car, cas, fl, gr, lu, sw |
| *A.(Agapostemon) splendens* (Lepeletier) | 10 | f,m | v | ba, car, gr, ho, lu |
| *A. (Agapostemon) texanus* Cresson | 46 | m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *A.(Agapostemon) virescens* (F.) | 7 | f | v | ba, car, |
| *Halictus* spp. Latreille | 29 | f | v | ba, cr, car, fl, gr, ho, lu, sw |
| *H.(Nealictus) parallelus* Say | 16 | f | v | car, fl, gr |
| *H.(Odontalictus) ligatus* Say | 328 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *H.(Protohalictus) rubicundus* | 28 | f,m | v | ba, car, cas, gr, ho, lu |

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| (Christ) | | | | |
| *H.(Seladonia) tripartitius* Cockerell | 43 | f | n,v | ba, br, lu |
| *Lasioglossum* spp. Curtis | 826 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *L. (Dialictus)* | 2846 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *L. (Dialictus) semicaeroleum* (Cockerell) | 2 | f | v | car, fl |
| *L.(Evylaeus)* | 1 | f | n | fl |
| *L. (Lasioglossum)* | 250 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *L. (Lassioglossum) bardum* (Cresson) | 1 | f | v | br |
| *L. (Lasioglossum) sisymbrii* (Cresson) | 1 | m | v | fl |
| *L. (Sphecodogastra) lusorium* (Cresson) | 1 | f | v | ba |
| *L.(Sphecodogastra)* | 54 | f,m | v | ba, br, car, cas, fl, ho, lu |
| *Sphecodes* spp. Latreille | 30 | f,m | v | ba, br, cas, fl, gr, ho, lu, sw |
| MELITTIDAE Schenck | | | | |
| DASYPODAINAE Börner | | | | |
| Dasypodaini Börner | | | | |
| *Hesperapis* sp. Cockerell | 19 | f | v | ba, br, car, gr, ho |
| MEGACHILIDAE Latreille | 3 | | v | ba, cas, fl |
| LITHURGINAE | | | | |
| *Lithurgus chrysurus* Fonscolombe | 4 | f | v | cas |
| MEGACHILINAE Latreille | | | | |
| Lithurgini Newman | | | | |
| *Lithurgopsis littoralis* Cockerell | 80 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| Osmiini Newman | | | | ba, br, car, cas, fl, ho, lu, sw |
| *Ashmeadiella* sp. Cockerell | 70 | f,m | v | ba, br, car, cas, fl, ho, lu, sw |
| *A. (Ashmeadiella) gilletei* Titus | 23 | f | n,v | cas, fl, ho |
| *A. (Ashmeadiella) meliloti* (Cockerell) | 4 | f | v | car, cas, gr, ho |
| *Hoplitis* sp. Klug | 2 | f | v | gr |
| *H. (Alcidamea) pilosifrons* (Cresson) | 11 | f | v | ba, br, ho |
| *Osmia* spp. | 291 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *O.(Melanosmia)* | 42 | f,m | v | ba, br, car, cas, fl, gr |
| *O.(Diceratosmia)subfasciata* | 5 | f,m | v | cas, fl, ho |

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|---|---|---|---|---|
| Cresson | | | | |
| Anthidiini Ashmead | | | | |
| *Anthidium* sp. Cockerell | 48 | f,m | v | ba, br, car, cas, fl, gr, lu, sw |
| *A.(Anthidium) maculifrons* Smith | 1 | m | v | lu |
| *A.(Anthidium) porterae* Cockerell | 90 | f,m | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *A.(Anthidium) schwarzi* Gonzalez and Griswold | 1 | m | v | gr |
| *Dianthidium* spp. Cockerell | 69 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *D.(Dianthidium) curvatum* (Smith) | 8 | m | v | br, car, cas, fl, lu |
| *D.(Dianthidium) parvum* (Cresson) | 2 | f,m | v | fl, gr |
| Megachilini Latrielle | 2 | | v | fl |
| *Coelioxys* spp. Latreille | 13 | f,m | n,v | ba, car, cas, fl, ho |
| *C.(Boreocoelioxys) octodentata* Say | 1 | f | v | gr |
| *C.(Boreocoelioxys) sayi* Robertson | 1 | f | v | ho |
| *C. (Xerocoelioxys) mitchelli* Baker | 1 | f | v | ho |
| *C. (Xerocoelioxys) piercei* Crawford | 3 | f | v | br, cas |
| *Megachile* spp. Latrielle | 294 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M.(Argyropile)* | 18 | f,m | v | ba, br, car, cas, gr, ho, lu, sw |
| *Megachile (Argyropile) parallela* Smith | 2 | | n | br,gr |
| *M.(Litomegachile)* | 16 | f,m | v | ba, car, fl, gr, ho, lu, sw |
| *M.(Litomegachile) brevis* Say | 8 | f,m | v | car, fl, ho |
| *M. (Litomegachile) gentilis* Cresson | 1 | f | v | fl |
| *M.(Litomegachile) texana* Cresson | 1 | m | v | ba |
| *M.(Megachile)* | 41 | f,m | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *M.(Megachile) montivaga* Cresson | 10 | f | v | ba, br, car, cas, fl, sw |
| *M.(Megachiloides)* | 137 | f,m | v | ba, br, car, cas, fl, gr, ho, sw |
| *M. (Megachiliodes) amica* Cresson | 5 | f | v | car, cas, gr, sw |
| *M. (Sayapis) policaris* Say | 1 | | n | br |
| *M.(Xanthosarus)* | 7 | f | v | ba, br, gr, ho, lu, sw |
| SPHECOIDEA | | | | |
| ASTATIDAE | 1 | | v | ho |
| CRABRONIDAE Latreille | 93 | | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ASTATINAE Lepeletier de Saint Fargeau | | | | |

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| *Astata* sp. Latreille | 1 | n | ho |
| BEMBICINAE Latreille | 3 | v | ba |
| Bembicini | | | |
| Stizina | | | |
| *Stizoides* sp. Guérin-Méneville | 2 | v | ba, car |
| *S. renicinctus* (Say) | 3 | n | lu |
| Bembicina | 1 | v | gr |
| *Bembix* sp. F. | 8 | n,v | ba, car, ho |
| Gorytina Lepeletier de Saint Fargeau | 2 | v | car, lu |
| *Hoplisoides* sp. Gribodo | 1 | v | ba |
| Nyssonini Latreille | 7 | v | ba, br, cas, fl, gr, lu |
| CRABRONINAE Latreille | | | |
| Crabronini | 1 | n | sw |
| Larrini | 14 | n,v | ba, car, cas, gr, ho, sw |
| *Liris* sp. F. | 13 | v | gr |
| PEMPHREDONINAE Dahlbom | | | |
| Psenini | 1 | n | fl |
| PHILANTHIDAE | 1 | v | sw |
| PHILANTHINAE Dahlbom | 11 | v | ba, br, car, cas, fl, gr, ho, lu |
| Aphilanthopini | 8 | v | ba, cas |
| *Aphilanthops* sp. Patton | 2 | v | br, lu |
| Cercerini | 11 | v | br, car, cas, gr, fl |
| *Cerceris* sp. | 15 | n,v | ba, car, gr, ho, sw |
| *C.bicornuta* Guréin-Méneville | 2 | v | ba |
| *C. frontata* Say | 2 | v | ba |
| *Eucerceris* sp. Cresson | 20 | n,v | car, cas, fl, gr, ho |
| Philanthini | | | |
| *Philanthus* sp. Frabricius | 31 | n,v | ba, br, car, cas, fl, ho, sw |
| SPHAEROPHALMINAE Ashmead | 1 | n | fl, gr |
| SPHECIDAE Latreille | 144 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| AMMOPHILINAE | 248 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Podalonia* sp. Fernald | 7 | v | ba, cas, ho |
| SCELIPHRINAE Ashmead | 2 | v | car, sw |
| SPHECINAE | 4 | v | ba, br, fl, gr |
| Prionychini | | | |
| *Prionyx* sp. Van der Linden | 35 | n,v | ba, br, car, cas, fl, lu |
| Sphecini | | | |
| *Sphex* sp. L. | 1 | v | cas |
| SCOLIODEA | | | |
| SCOLIIDAE Leach | 13 | v | ba, br, cas, fl, ho, lu, sw |
| SCOLIINAE Latreille | 5 | n,v | lu, sw |

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| *Scolia* sp. | 6 | v | ba, br, car, fl |
| *Triscolia* sp. Saussure | 6 | v | ba, br, car |
| TIPHIIDAE Leach | 77 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| BRACHYCISTIDINAE | 30 | v | ba, br, car, cas, gr, ho, lu, sw |
| TIPHIINAE | 31 | n,v | br, car, gr, ho, lu, sw |
| METHOCHINAE | 1 | v | gr |
| THYNNIDAE | | | |
| MYZININAE | 7 | n,v | br, car, gr, ho |
| *Myzinum* spp. Latreille | 10 | v | ba, fl, gr, ho, lu, sw |
| MUTILLIDAE Andre | 41 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| POMPILOIDEA | | | |
| POMPILIDAE Latreille | 10 | v | br, cas, fl, gr, ho |
| PEPSINAE Lepeletier de Saint Fargeau | 1 | n | br |
| Aporini | | | |
| *Psorthaspis legata* (Cresson) | 2 | v | br |
| Pepsini | | | |
| *Pepsis* sp. F. | 8 | v | ba, br, cas, ho, lu |
| POMPILINAE | 7 | n,v | car, fl, gr, lu |
| Pompilini | | | |
| *Poecilopompilus* sp. Howard | 1 | n | ho |
| VESPOIDEA | | | |
| VESPIDAE Stephens | 15 | v | ba, br, car, cas, fl, ho, lu, sw |
| EUMENINAE Nugroho, Kojima, Ubaidillah | 499 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Eumenes* sp. | 4 | v | ba, ho, lu |
| *E. aureus* Isley | 10 | v | br, cas, fl, gr |
| *Euodynerus* spp. Bluthgen | 707 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Pterocheilus* sp. Klug | 534 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Stenodynerus* sp. Saussure | 136 | n,v | ba, br, car, cas, fl, ho, lu, sw |
| MASARINAE | | | |
| *Pseudomasaris* sp. Ashmead | 1 | v | ba |
| POLISTINAE | | | |
| *Polistes* sp. | 15 | n,v | ba, br, car, cas, fl, gr, ho, sw |
| *P. apachus* Saussure | 6 | v | br, ho, lu |
| *P. bellicosus* Cresson | 2 | v | fl, gr |
| FORMICOIDEA | | | |

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|---|---|---|---|
| FORMICIDAE Marazzi, Ane, Simon, Delgado-Salinas, Luckow and Sanderson | 803 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |

Table II.2. Coleoptera captured in the Southern High Plains of Texas in 2013–2014. N = number of specimens; v = blue vane capture; n = insect net capture; ba = Bailey County, br = Briscoe County, car = Carson County, cas = Castro County, fl = Floyd County, gr = Gray County, ho = Hockley County, lu = Lubbock County, sw = Swisher County

| Coleoptera taxa | N | Capture Method | County |
|---|---|---|---|
| COLEOPTERA | 21 | v | br, car, cas, gr, ho, lu, sw |
| ADEPHAGA | | | |
| CARABIDAE Latreille | 244 | n,v | ba, br,car, cas, fl, gr, ho, lu, sw |
| Brachininae | 1 | v | br |
| *Brachinus* sp. Weber | 6 | v | br, fl, gr |
| *Cincindela* sp. L. | 1 | v | gr |
| *Colliuris* sp. (L.) | 2 | v | fl |
| *Lebia* sp. Latreille | 3 | v | ba, fl, gr |
| *L.bivittata* (F.) | 3 | v | ho, sw |
| *Stenolophus*sp. Dejean | 5 | v | cas, gr, ho, lu |
| HALIPLIDAE Aubé | 1 | v | sw |
| *Halipus* sp. Latreille | 1 | v | lu |
| DYTISCIDAE Leach | 1 | v | sw |
| POLYPHAGA | | | |
| HYDROPHILOIDEA | | | |
| HYDROPHILIDAE Latreille | 45 | v | ba, br, cas, fl, gr, ho, lu, sw |
| HYDROPHILINAE | | | |
| Hydrophilini | | | |
| *Tropisternus* sp. Solier | 3 | v | cas, lu |
| SPHAERIDIINAE | | | |
| *Sphaeridium scarabaeoides* L. | 2 | v | gr, lu |
| HISTERIDAE Gyllenhaal | 5 | v | br, cas, fl, gr, lu |
| HISTERINAE | | | |
| Histerini | | | |
| *Spilodiscus* sp. Lewis | 5 | v | br, car, gr, sw |
| STAPHYLINOIDEA | | | |
| HYDRAENIDAE Mulsant | 1 | v | ba |
| STAPHYLINIDAE Latreille | 24 | v | br, car, cas, fl, gr, ho, lu, sw |
| SCARABAEOIDEA | | | |
| OCHODAEIDAE | | | |
| *Parochodaeus* sp. Nikolajev | | | |
| SCARABAEIDAE Latreille | 153 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| APHODIINAE Leach | 10 | v | car, cas, sw |
| CETONIINAE | | | |
| Cetoniini | | | |

| | | | |
|---|---|---|---|
| *Euphoria* sp. Burmeister | 20 | v | car, fl, gr, ho, lu |
| *E.kernii* Haldeman | 173 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| Cremastocheilini | | | |
| *Cremastocheilus quadricollis* (Casey) | 1 | v | lu |
| Trichiini | | | |
| *Trichiotinus* sp. Casey | 1 | v | lu |
| DYNASTINAE | | | |
| Pentodontini | | | |
| *Tomarus* sp. Erichson | 15 | v | ba, br, car, cas, fl, gr, ho, lu |
| MELOLONTHINAE MacLeay, Leach in Samouelle | 1 | v | br |
| Melolonthini | | | |
| *Hypotrichia* sp. LeConte | 7 | v | ba, br, car, cas, gr, sw |
| RUTELINAE | | | |
| Anomalini | | | |
| *Anomala* sp. Samouelle | 1 | v | cas |
| SCARABAEINAE | | | |
| Ateuchini | 1 | v | ho |
| Onthophagini | | | |
| *Digitonthophagus gazelle* (F.) | 1 | v | gr |
| BUPRESTOIDEA | | | |
| BUPRESTIDAE Leach | 200 | n,v | ba, br, ca |
| POLYCESTINAE Lacordaire | 1 | v | fl |
| *Acmaeodera* sp. Eschscholtz | 182 | n,v | ba, br, cas, fl, gr, ho, lu, sw |
| *A. gibbula* LeConte | 1 | v | br |
| *A. robigo* Knull | 59 | v | ho, lu, sw |
| *Chrysobothris* sp. Eschscholtz | 2 | v | lu, sw |
| *C. lateralis* Waterhouse | 1 | v | ho |
| ELATEROIDEA | | | |
| THROSCIDAE Laporte | 2 | v | fl |
| ELATERIDAE Leach | 35 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| LAMPYRIDAE Rafinesque | 2 | v | car |
| Lucidotini | | | |
| *Ellychnia* sp. Blanchard | 1 | v | gr |
| CANTHARIDAE Imhoff | 11 | v | br, fl,lu |
| CHAULIOGNATHINAE LeConte | | | |
| Chauliognathini | | | |
| *Belotus* sp. Gorham | 1 | v | lu |
| *Chauliognathus* sp. Hentz | 2150 | v | br, car, fl, gr, ho, lu, sw |
| *C. basalis* LeConte | 1845 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *C. limbicollis* LeConte | 48 | n,v | br, car, fl, gr, lu |

| | | | |
|---|---|---|---|
| *C. scutellaris* LeConte | 33 | n,v | br, fl, gr |
| DERODONTOIDEA | | | |
| ANOBIIDAE Reitter | 1 | v | fl |
| CLEROIDEA | | | |
| CLERIDAE Latreille | 49 | v | ba, cas, fl, ho, lu |
| CLERNINAE | | | |
| *Enoclerus* sp. Gahan | 22 | v | ba, car, cas, gr, lu |
| *E. spinolea* (LeConte) | 14 | v | ba, car, cas, gr, sw |
| *Trichodes* sp. Herbst | 11 | v | ba, fl, gr |
| *T. bibalteatus* LeConte | 2 | v | fl, lu |
| HYDNOCERINAE | | | |
| *Phyllobaenus* sp. Dejean | 26 | v | ba, br, car, cas, fl, ho, lu, sw |
| TILLINAE | | | |
| *Cymatodera* sp. Gray | 1 | v | lu |
| MELYRIDAE Leach | 42 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| DASYTINAE Laporte de Castelnau | | | |
| Listrini Majer | | | |
| *Listrus* sp. Motschulsky | 1 | n | lu |
| *Sydates* sp. Casey | 1 | n | car |
| *Trichochrous* sp. Motschulsky | 5 | n | ho |
| MALACHIINAE | | | |
| Malachiini | | | |
| *Collops* sp. Erichson | 39 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *C. balteatus* LeConte | 1 | v | lu |
| *C. limbellus* Gemminger and Harold | 13 | v | ba, br, car, fl, gr, ho, lu |
| *C. marginicollis* LeConte | 19 | v | ba, br, cas |
| *C. quadrimaculatus* (F.) | 26 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *C. vittatus* (Say) | 21 | v | ba, br, car, cas, fl, gr, ho, lu |
| CUCUJOIDEA | | | |
| NITIDULIDAE Latreille | 496 | v | ba, br, car, cas, fl, gr, lu, sw |
| CARPOPHILINAE | | | |
| *Carpophilus* sp. Stephens | 389 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| PHALACRIDAE Leach | 4 | v | ba, ho, sw |
| TENEBRIONOIDEA | | | |
| COCCINELIDAE Latreille | 86 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| COCCINELINAE | | | |
| *Coccinella septempunctata* L. | 4 | v | ba, br, car, sw |
| *Hippodamia* sp. Dejean | 2 | v | fl, gr |

| | | | |
|---|---|---|---|
| *H. convergens* Guerin | 109 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *H. sinuata* Mulsant | 3 | v | car, cas |
| *Olla v-nigram* (Mulsant) | 4 | v | ba, cas, fl |
| SCYMNINAE | | | |
| Hyperaspidini | | | |
| *Hyperaspidius* sp. Crotch | 4 | v | ba, cas, fl |
| Scymnini | | | |
| *Scymnus* sp. Kugelann | 2 | n,v | br |
| MYCETOPHAGIDAE Leach | 1 | v | ho |
| MORDELLIDAE Latrielle | 53 | v | ba, br, car, fl, ho, lu, sw |
| Mordellini | | | |
| *Mordella* sp. L. | 14 | n,v | br, fl, lu, sw |
| Mordellistenini | | | |
| *Mordellina* sp. Schilsky | 1 | v | ba |
| *Mordellistena* sp. Costa | 11 | v | ba, br, cas, gr |
| RIPIPHORIDAE | | | |
| RIPIPHORINAE | | | |
| *Macrosiagon* sp. Hentz | 1 | v | gr |
| TENEBRIONIDAE Latreille | 64 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ALLECULINAE | | | |
| *Hymenorus* sp. | 2 | n,v | br |
| PIMELIINAE | | | |
| Epitragini | | | |
| *Bothrote*s sp. Casey | 6 | n,v | br, fl, lu |
| MELOIDAE Gyllenhall | 1884 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| MELOINAE | 1 | v | fl |
| *Lytta* sp. F. | 4 | n,v | lu |
| *L. biguttata* LeConte | 9 | n,v | ba, cas, ho, lu |
| *L. fulvipennis* LeConte | 4 | v | gr, lu |
| *Pyrota* sp. LeConte | 9 | n,v | fl, lu |
| *P. bilineata* Horn | 5 | v | ba, gr, ho |
| *P. perversa* Dillon | 1 | v | sw |
| Epicautini | | | |
| *Epicauta* sp. Dejean | 3623 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *E. albida* (Say) | 2 | v | fl |
| *E. andersoni* Werner | 1 | v | br |
| *E. atrata* (F.) | 138 | v | ba, br, car, fl, gr, ho, lu, sw |
| *E. callosa* LeConte | 2205 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *E. ferruginea* (Say) | 414 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *E. immaculata* Say | 1 | v | car |

| | | | |
|---|---|---|---|
| *E. maculata* (Say) | 25 | n,v | br, car, cas, fl, gr, sw |
| *E. sericans* LeConte | 4757 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| Nemognathini | | | |
| *Gnathium* sp. Kirby | 18 | n,v | gr |
| *Nemognatha* sp. Illiger | 26 | n,v | ba, car, fl, lu |
| *N. bifoveata* Enns | 1 | v | ho |
| *N. lurida* LeConte | 16 | v | ba, br, car, fl, gr, lu, sw |
| *N. piazata bicolor* LeConte | 1 | v | ba |
| *Zonitis* sp. F. | 35 | n,v | br, cas, car, fl, ho, lu, sw |
| *Z. cribricollis* (LeConte) | 2 | v | car, gr |
| *Z. vittigera* (LeConte) | 58 | v | ba, br, car, cas, fl, gr, ho, lu |
| ANTHICIDAE Latreille | 3 | v | car, cas |
| *Notoxus calcaratus* Horn | 574 | v | ba, br, car, cas, gr, fl, ho, lu, sw |
| ADERIDAE Csiki | 10 | v | ba, br, car, fl, ho, lu, sw |
| *Aderus* sp. Westwood | 1 | v | car |
| SCRAPTIIDAE Gistel | 11 | v | ba, car, fl, sw |
| CHRYSOMELOIDEA | | | |
| CERAMBYCIDAE Latreille | 23 | v | ba, car, cas, fl, gr, lu |
| *Anopliomorpha rinconium* (Casey) | 1 | n | |
| *Batyle* sp. Thomson | 6 | n,v | car, ho, lu |
| *Crossidius* sp. Casey | 7 | n,v | car, fl |
| *C. sayi bilenticulatus* | 1 | n | ba |
| *Estoloides* sp. Breuning | 1 | n | cas |
| *Monochamus*sp. Dejean | 1 | v | car |
| *Sphaenothecus bivittatus* | 22 | n,v | lu |
| *Typocerus* sp. LeConte | 89 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| CHRYSOMELIDAE | 100 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| BRUCHINAE Latreille | 86 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| Bruchini | 1 | v | cas |
| *Bruchus rufimanus* Boheman | 2 | v | fl, ho |
| *Megacerus* sp. Fåhraeus | 1 | v | gr |
| CASSIDINAE Gyllenhal | 15 | v | br, cas, fl, ho, lu, sw |
| Cassidini | 15 | v | br, cas, fl, gr, ho, sw |
| *Charidotella sexpunctata* (F.) | 1 | v | car |
| Chalepini Weise | 1 | v | fl |
| *Stenopodius* sp. Horn | 1 | n | lu |
| Chrysomelini | | | |
| *Plagiodera* sp. Chevrolat | 1 | v | ho |
| Clytrini Lacordaire | 11 | v | car, cas, gr, ho, lu |
| *Saxinis* sp. Lacordaire | 7 | v | cas |

| | | | |
|---|---|---|---|
| Cryptocephalini Clavareau | 1 | v | gr |
| GALERUCINAE Latreille | 1 | v | cas |
| Alticini Newman | 25 | n,v | ba,car, cas, fl, gr, ho, sw |
| *Chaetocnema* sp. Stephens | 3 | n,v | lu |
| *Disonycha triangularis* (Say) | 1 | n | fl |
| Galerucini Latreille | 6 | v | car, fl, gr |
| Luperini | | | |
| *Diabrotica* sp. Chevrolat | 2 | v | cas, gr |
| *D. undecimpunctata* (L.) | 16 | n,v | ba, br, car, cas, ho, sw |
| CURCULIONOIDEA | | | |
| ANTHRIBIDAE Billberg | 1 | v | cas |
| ATTELABIDAE Billberg | 5 | v | br, car, fl |
| *Haplorhynchites* sp. Voss | 11 | n | cas |
| CURCULIONIDAE Latreille | 50 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |

Table II.3. Diptera captured in the Southern High Plains of Texas in 2013–2014. N = number of specimens; v = blue vane capture; n = insect net capture; ba = Bailey County, br = Briscoe County, car = Carson County, cas = Castro County, fl = Floyd County, gr = Gray County, ho = Hockley County, lu = Lubbock County, sw = Swisher County

| Diptera taxa | N | Capture Method | County |
|---|---|---|---|
| DIPTERA | 175 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| NEMATOCERA | | | |
| CERATOPOGONIDAE Newman | 1 | v | fl |
| CHIRONOMIDAE Newman | 8 | v | br, cas, fl, ho, lu, sw |
| CULICIDAE Meigen | 106 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| SIMULIIDAE Newman | 9 | v | ba, fl, ho |
| BIBIONOMORPHA | | | |
| BIBIONIDAE Newman | 2 | v | car, sw |
| CECIDIOMYIIDAE Newman | 10 | v | ba, car, cas, fl, lu, sw |
| MYCETOPHILIDAE Newman | 5 | v | cas, fl, |
| SCIARIDAE Billberg | 2 | v | br, cas, lu |
| *Eugnoriste* sp. Coquillett | 69 | n,v | ba, lu, sw |
| BRACHYCERA | | | |
| STRATIOMYOMORPHA | | | |
| STRATIOMYIDAE Latreille | 1 | v | lu |
| STRATIOMYINAE | | | |
| Stratiomyini | | | |
| *Odontomyia* sp. Meigen | 1 | v | cas |
| ANTHERICIDAE | 1 | v | sw |
| RHAGIONIDAE | | | |
| *Symphoromyia* sp. Kerr | 1 | v | ho |
| TABANIDAE Latreille | 3 | v | car, fl |
| TABANINAE | | | |
| Tabanini | | | |
| *Agkistrocerus* spp. Phillip | 2 | v | car, gr |
| *Hamatabanus* sp. Phillip | 1 | v | sw |
| MUSCOMORPHA | | | |
| ASIOIDEA | | | |
| ASILIDAE Ricardo, Gertrude and Theobald | 15 | v | car, cas, fl, gr, ho, lu, sw |
| ASILINAE Schiner | 1 | v | lu |
| STENOPOGONINAE | | | |
| *Heteropogon* sp. Loew | 1 | n | sw |
| Prolepsis tristis (Walker) | 1 | v | lu |
| BOMBYLIIDAE Becker | 182 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ANTHRACINAE | | | |

| | | | |
|---|---|---|---|
| Exprosopini | | | |
| *Exoprosopa* sp. Macquart | 6 | n,v | car, ho |
| Villini | | | |
| *Chrysanthrax* sp. Osten-Sacken | 1 | n | cas |
| *Lepidanthrax* sp. Osten-Sacken | 1 | n | car |
| *Paravilla* sp. Painter | 3 | n | br, gr |
| *Poecilanthrax* sp. Osten-Sacken | 1 | n | cas |
| *Villa* sp. Lioy | 1 | n | ho |
| BOMBYLIINAE | | | |
| Bombyliini | | | |
| *Anastoechus* spp. Osten-Sacken | 151 | n,v | ba, br, car, cas, fl, gr, ho, sw |
| *Heterostylum* spp. Macquart | 7 | n,v | fl, ho, lu, sw |
| Conophorini | | | |
| *Lordotus* spp. Loew | 5 | n,v | ba |
| PTHIRIINAE | | | |
| Poecilognathini | | | |
| *Poecilognathus* spp. Jaennicke | 190 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *P. (Phthiria)* spp. Meigen | 27 | v | ba, cas, ho, sw |
| TOXOPHORINAE | | | |
| *Geron (Geron)* sp. Meigen | 84 | n,v | ba, br, car, cas, fl, ho, lu, sw |
| *Toxophora* spp. Meigen | 2 | v | ba, gr |
| MYTHICOMYIIDAE Melander | | | |
| *Mythicomyia* sp. Coquillett | 1 | n | lu |
| THEREVIDAE Newman | 2 | v | cas, ho |
| THREVINAE | | | |
| *Ozodiceromya* sp. Bigot | 1 | n | cas |
| EMPIDOIDEA | | | |
| HYBOTIDAE Macquart | 4 | v | car, cas, sw |
| TACHYDROMIINAE | | | |
| *Drapetis* sp. Melander | 5 | n | gr, sw |
| CYCLORRAPHA | | | |
| ASCHIZA | | | |
| PHORIDAE Curtis | 9 | v | ba, car, cas, ho, lu |
| PIPUNCULIDAE Walker | 45 | v | ba, cas, fl, ho, lu |
| CHALARINAE | 1 | v | sw |
| Pipunculini | 72 | v | ba, br, car, cas, fl, gr, ho, sw |
| SYRPHIDAE Latreille | 269 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ERISTALINAE | | | |
| Eristalini | | | |
| *Eristalinus aeneus* (Scopoli) | 4 | n,v | ba, car |
| *Eristalis* spp. Latreille | 9 | v | br, car, gr |

| | | | |
|---|---|---|---|
| *E. stipator* Osten Sacken | 283 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Helophilus* spp. Meigen | 366 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Palpada vinetorum* (F.) | 2 | n | fl, sw |
| *Syritta flaviventris* Macquart | 1 | n | ho |
| *S. pipiens* (L.) | 2 | v | cas, lu |
| Rhingiini | | | |
| *Rhingia* sp. Scopali | 1 | v | ba |
| Volucellini | | | |
| *Copestylum* sp. Macquart | 3 | v | car, cas, ho |
| *C. mexicanum* (Macquart) | 1 | v | car |
| SYRPHINAE | | | |
| Bacchini | | | |
| *Platycheirus* sp. Lepeletier and Serville | 2 | v | ho |
| Syrphini | | | |
| *Allograpta* sp. Osten-Sacken | 10 | v | br, car, cas, gr |
| *A. exotica* Wiedemann | 11 | n,v | ba, car, gr, sw |
| *A. obliqua* Say | 61 | n,v | ba, br, cas, fl, gr, ho, lu, sw |
| *Eupeodes* sp. Matsumura | 1 | v | ba, gr |
| *E. (Metasyrphus)* Matsumura | 1 | v | ba, |
| *E. volucris* Osten Sacken | 71 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Pseudodoros clavatus* (F.) | 1 | n | car |
| *Sphaerophoria* sp. Lepeletier and Serville | 1 | v | sw |
| *Syrphus* sp. F. | 1 | v | ba |
| Toxomerini | | | |
| *Toxomerus* sp. Macquart | 48 | n,v | ba, br, car, cas, fl, gr, ho, sw |
| CALYPTERATAE | | | |
| ANTHOMYIIDAE Robineau-Desvoidy | 71 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Botanophila* sp. Lioy | 1 | n | cas |
| Leucophora sp. Robineau-Desvoidy | 4 | n | sw |
| CALLIPHORIDAE Brauer and Bergenstamm | 17 | n,v | ba, br, car, cas, ho, sw |
| CHRYSOMYINAE | | | |
| *Cochliomyia* sp. Townsend | 1 | n | fl |
| *Phormia regina* Meigen | 1 | v | sw |
| *Protophormia* sp. Townsend | 5 | v | ba, cas |
| MELANOMYIINAE | | | |
| *Angioneura* sp. Brauer and Bergenstamm | 1 | n | ho |
| *Lucilia* spp. Robineau-Desvoidy | 6 | v | ba, car, ho, lu |

| | | | |
|---|---|---|---|
| FANNIIDAE Townsend | | | |
| *Fannia* sp. Schnabl and Dziedzicki | 2 | n | cas |
| MUSCIDAE Latreille | 33 | n,v | ba, car, cas, fl, ho, lu, sw |
| MYDAEINAE | | | |
| *Graphomya* sp. Robineau-Desvoidy | 2 | n,v | fl |
| MUSCINAE | | | |
| Muscini | | | |
| *Neomyia cornicina* (F.) | 3 | n,v | cas, fl |
| OESTRIDAE Leach | 2 | v | cas |
| SARCOPHAGIDAE Macquart | 33 | n,v | ba, br, car, cas, fl, gr, sw |
| MILTOGRAMMINAE Meigen | 2 | v | cas, sw |
| SARCOPHAGINAE | | | |
| Ravinia sp. Robineau-Desvoidy | 2 | n | fl, gr |
| SCATHOPHAGIDAE Robineau-Desvoidy | 4 | v | ba |
| TACHINIDAE Robineau-Desvoidy | 242 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| DEXIINAE | | | |
| Dexiini | | | |
| *Microchaetina* sp. van der Wulp | 1 | n | sw |
| Ptilodexia sp. Bauer and Bergenstamm | 1 | n | car |
| EXORISTINAE | | | |
| Exoristini | | | |
| *Chetogena* sp. Rodani | 1 | n | ho |
| Goniiini | | | |
| *Gonia* spp. Meigen | 29 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Onychogonia* sp. Bauer and Bergenstamm | 1 | n | fl |
| PHASIINAE | | | |
| Catharosiini | | | |
| *Catharosia* spp. Rondani | 172 | n,v | ba, br, car, cas, fl, gr, ho, sw |
| Cylindromyiini | | | |
| *Cylindromyia* sp. Meigen | 3 | n,v | car, gr, ho |
| Gymnosomatini | | | |
| *Gymnosoma* spp. Meigan | 11 | n,v | ba, br, car, cas, gr |
| TACHININAE | | | |
| Tachinini | | | |
| *Archytas* spp. Jaennicke | 14 | n,v | cas, fl, gr |
| ACALYPTRATAE | | | |
| DIOPSOIDEA | | | |
| TANYPEZIDAE Rondani | 4 | v | ba, sw |
| CONOPOIDEA | | | |
| CONOPIDAE Latreille | 34 | v | ba, br, car, cas, fl, gr, ho, lu, sw |

| | | | |
|---|---|---|---|
| MYOPIAE | 1 | v | gr |
| *Myopa* sp. Meigen | 1 | v | cas |
| *Thecophora* spp. Rondani | 83 | n,v | br, car, cas, fl, gr, ho, lu, sw |
| *Zodion* spp. Latreille | 52 | n,v | ba, br, car, cas, fl, gr, ho, lu |
| TEPHRITOIDEA | | | |
| TEPHRITIDAE Newman | 5 | v | car, gr, fl, sw |
| TEPHRETINAE | | | |
| Tephritini | | | |
| Campiglossa sp. Rodani | 4 | n,v | br |
| TRYPETINAE | | | |
| Carpomyini | | | |
| *Zonosemata* sp. Benjamin | 4 | v | br, cas, gr |
| ULIDIIDAE Macquart | 5 | v | cas, gr, ho, lu, sw |
| OTITINAE | | | |
| Myennidini | | | |
| *Oedopa* sp. Loew | 1 | v | cas |
| SCIOMYZOIDEA | | | |
| SEPSIDAE Walker | 2 | v | cas, sw |
| *Sepsidimorpha* sp. Frey | 1 | n | cas |
| OPOMYZOIDEA | | | |
| CLUSIIDAE Handlirsch | 3 | v | cas, sw |
| CARNOIDEA | | | |
| CHLOROPIDAE Rondani | 66 | n,v | br, car, cas, fl, gr, sw |
| CHLOROPINAE | | | |
| *Thaumatomyia* spp. Zenker | 8 | v | ba, car, cas, gr |
| SPHAEROCEROIDEA | | | |
| HELEOMYZIDAE Westwood | 1 | n | gr |
| SPHAEROCINIDAE Janssen and Maxwell | 2 | v | ba, cas |
| EPHYDROIDEA | | | |
| DROSOPHILIDAE Rondani | 6 | v | ba, cas, fl |
| EPHYDRIDAE Zetterstedt | 3 | v | ba, sw |
| ACROCERIDAE Leach | 3 | v | ba, gr |
| *Ogcodes* sp. Latreille | 3 | v | ba,gr |

Table II.4. Lepidoptera captured in the Southern High Plains of Texas from 2013–2014. N = number of specimens; v = blue vane capture; n = insect net capture; ba = Bailey County, br = Briscoe County, car = Carson County, cas = Castro County, fl = Floyd County, gr = Gray County, ho = Hockley County, lu = Lubbock County, sw = Swisher County

| Lepidoptera taxa | N | Capture Method | County |
|---|---|---|---|
| LEPIDOPTERA | 215 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| INCURVARIOIDEA | | | |
| PRODOXIDAE Riley | 1 | v | sw |
| YPONOMEUTOIDEA | | | |
| HELIODINIDAE | 38 | n,v | cas |
| GELECHIOIDEA | 1 | v | ho |
| ELACHISTIDAE Bruand | | | |
| ELACHISTINAE Bruand | | | |
| *Elachista* sp. Treitschke | 4 | n | br, fl |
| GELECHIIDAE Stainton | 51 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| GELECHIINAE Stainton | 2 | n | car |
| TORTRICIDAE Latreille | 5 | v | ba, car, cas |
| PTEROPHOROIDEA | | | |
| PTEROPHORIDAE Pagenstecher | 1 | v | br |
| PYRALOIDEA | | | |
| PYRALIDAE L. | 50 | n,v | ba, br, car, cas, gr, ho, lu, sw |
| CRAMBIDAE Latreille | 13 | n,v | ba, br, cas, fl, sw |
| SPILOMELINAE Guenee | | | |
| *Diastictis* sp. Huebner | 1 | v | cas |
| *Herpetogramma* sp. Lederer, Wien ent. Monats | 3 | v | cas, gr |
| ODONTIINAE | | | |
| Odontiini | | | |
| *Microtheoris vibicalis* (Zeller) | 2 | v | cas, sw |
| HESPERIOIDEA | | | |
| HESPERIIDAE Latreille | 102 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| HESPERIINAE Latreille | | | |
| *Anatrytone logan* Edwards | 17 | v | ba, br, car, gr, ho, lu |
| *Atalopedes campestris* Boisduval | 48 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Copaeodes aurantiaca* Hewitson | 3 | v | ba, lu |
| *Hesperia attalus* Edwards | 5 | v | br |
| *H. ottoe* Edwards | 1 | v | cas |
| *H. uncas* Edwards | 58 | v | ba, br, car, cas, gr, ho, sw |

| | | | |
|---|---|---|---|
| *Lerodea eufala* Edwards | 6 | n,v | car, cas, gr, lu |
| PYRGINAE Burmeister | | | |
| *Pholisora catullus* (F.) | 32 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| *Pyrgus communis* Evans | 6 | n,v | cas |
| PAPILIONOIDEA | | | |
| PIERIDAE Duponchel | 6 | v | cas, lu, sw |
| COLIADINAE Swainson | | | |
| *Colias eurytheme* Boisduval | 3 | n,v | cas, fl |
| *C. philodice* Godart | 1 | v | cas |
| *Eurema (Abaeis) nicippe* (Cramer) | 3 | v | ba, cas, lu |
| *Nathalis iole* Boisduval | 30 | n,v | br, car, cas, fl, ho, sw |
| PIERINAE | | | |
| Anthocharidini | | | |
| *Euchloe olympia* (Edwards) | 2 | v | br, sw |
| Pierini | | | |
| *Pontia* sp. L. | 1 | v | cas |
| *P. protodice* (Boisduval and LeConte) | 5 | n | cas, fl, gr, ho, lu |
| LYCAENIDAE Leach | 4 | v | fl, ho |
| POLYOMMATINAE Swainson | | | |
| *Brephidium exilis* sp. (Boisduval) Scudder | 3 | n | br, ho |
| *Echinargus isola* sp. Reakirt | 4 | n | ho,lu |
| *Plebejus acmon* sp. Westwood | 6 | v | fl, gr |
| NYMPHALIDAE Burgess | | | |
| APATURINAE | | | |
| Apaturini | | | |
| *Asterocampa celtis* (Boisduval and LeConte) | 1 | v | br |
| HELICONIINAE | | | |
| Argynnini | | | |
| *Euptoieta claudia* Gunder | 5 | v | car, cas, ho, lu |
| NYMPHALINAE | | | |
| Melitaeini | | | |
| *Phyciodes phaon* Hall | 2 | v | fl |
| *P. picta* Edwards | 2 | v | gr, sw |
| *P. tharos* Dos Passos | 1 | v | ho |
| Nymphalini | | | |
| *Vanessa atalanta* (L.) | 1 | v | ho |
| *V. cardui* Lempke | 1 | v | sw |
| GEOMETROIDEA | | | |
| GEOMETRIDAE Leach | 4 | v | fl, sw |
| BOMBYCOIDEA | | | |
| SPHINGIDAE Latreille | 3 | v | br, car, sw |
| MACROGLOSSINAE Gray | | | |
| Macroglossini | | | |

| | | | |
|---|---|---|---|
| *Darapsa myron* (Cramer) | 8 | v | cas, fl, gr, lu |
| *Hyles lineata* (F.) | 30 | n,v | ba, br, car, cas, fl, gr, lu, sw |
| *Proserpinus juanita* Strecker | 3 | v | cas, gr, lu |
| NOCTUOIDEA | | | |
| EREBIDAE Leach | 1 | n | lu |
| ARCTIINAE Kiriakoff | 2 | v | gr, ho |
| Arctiini Forbes | 2 | v | ba |
| *Estigmene acrea* | 2 | v | ba, lu |
| NOTODONTIDAE Stephens | 3 | v | cas, gr |
| NOCTUIDAE Kitching | 821 | n,v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ACONTIINAE | | | |
| Acontiini | | | |
| *Ponometia* sp. Herrich-Schäffer | 11 | v | fl, gr, lu |
| *Tarache* sp. Hübner | 4 | v | br, fl, ho, sw |
| NOCTUINAE | | | |
| Hadenini Guenee | 38 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| Noctuini Latreille | | | |
| *Feltia* sp. Lafontaine and Schmidt | 5 | v | car, gr |
| *F. jaculifera* (Guenee) | 58 | v | ba, br, car, cas, fl, gr, lu, sw |
| *Hemieuxoa* sp. McDunnough | 1 | v | car |

Table II.5. Other Orders captured in the Southern High Plains of Texas in 2013–2014. N = number of specimens; v = blue vane capture; n = insect net capture; ba = Bailey County, br = Briscoe County, car = Carson County, cas = Castro County, fl = Floyd County, gr = Gray County, ho = Hockley County, lu = Lubbock County, sw = Swisher County

| Taxa | N | Capture Method | County |
|---|---|---|---|
| ARANAE | 93 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| BLATTODEA | 1 | v | gr |
| EPHEMEROPTERA | 1 | v | car |
| HEMIPTERA | 895 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| CICADELLIDAE Latreille | 2 | v | fl, lu |
| NEUROPTERA | 61 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| CHRYSOPIDAE Schneider | 28 | v | ba, br, car, cas, fl, gr, ho, sw |
| HEMEROBIIDAE Latreille | 1 | n | ba |
| MANTISPIDAE Leach | 1 | v | car |
| ODONATA | 2 | v | ba |
| ORTHOPTERA | 52 | v | ba, br, car, cas, fl, gr, ho, lu, sw |
| ACRIDIDAE | 1 | v | ba |
| GRYLLIDAE Latreille | 1 | v | car |
| THYSANOPTERA | 60 | v | br, fl, gr |
| TRICHOPTERA | 1 | v | fl |

Table II.6. Frequency of insect orders collected in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties, TX by capture method (vane trap and insect net) in 2013–2014. Hym. = Hymenoptera, Cole. = Coleoptera.

| Capture Method | | *Hym.* | *Cole.* | *Diptera* | *Lep.* | *Others* | Total |
|---|---|---|---|---|---|---|---|
| Vane | Count | 46,345 | 20,632 | 2,979 | 1,621 | 1,199 | 72,776 |
| | % Composition | 63.68% | 28.35% | 4.09% | 2.23% | 1.65% | |
| Net | Count | 501 | 603 | 343 | 133 | 1 | 1,581 |
| | % Composition | 31.69% | 38.14% | 21.7% | 8.41% | 0.06% | |
| Total | Count | 46,846 | 21,235 | 3,322 | 1,754 | 1,200 | 74,357 |
| | % Composition | 63.0% | 28.56% | 4.47% | 2.36% | 1.61% | |

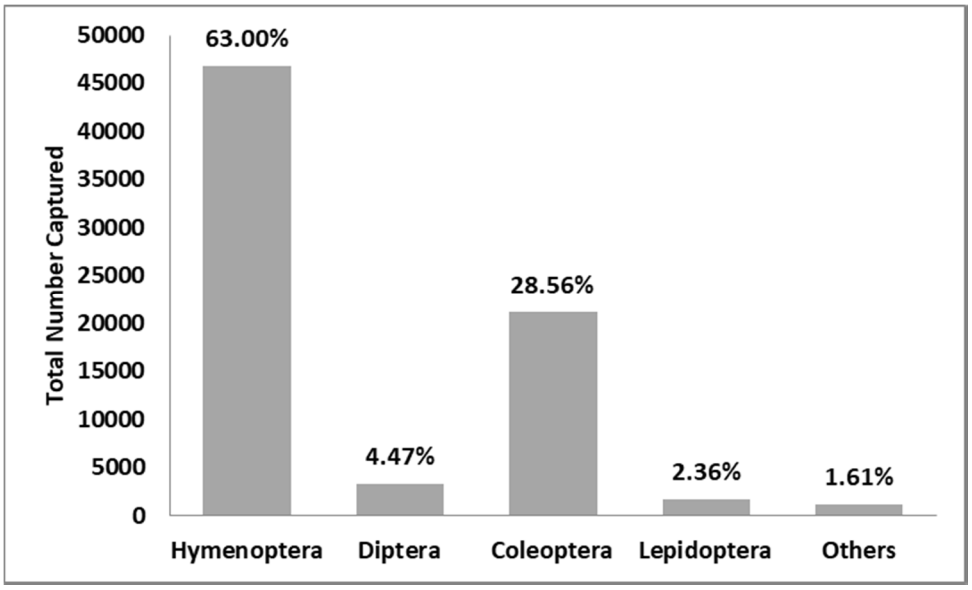



Figure II.2. Percentage of specimens (N = 74,358) collected in 2013–2014 by Order with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

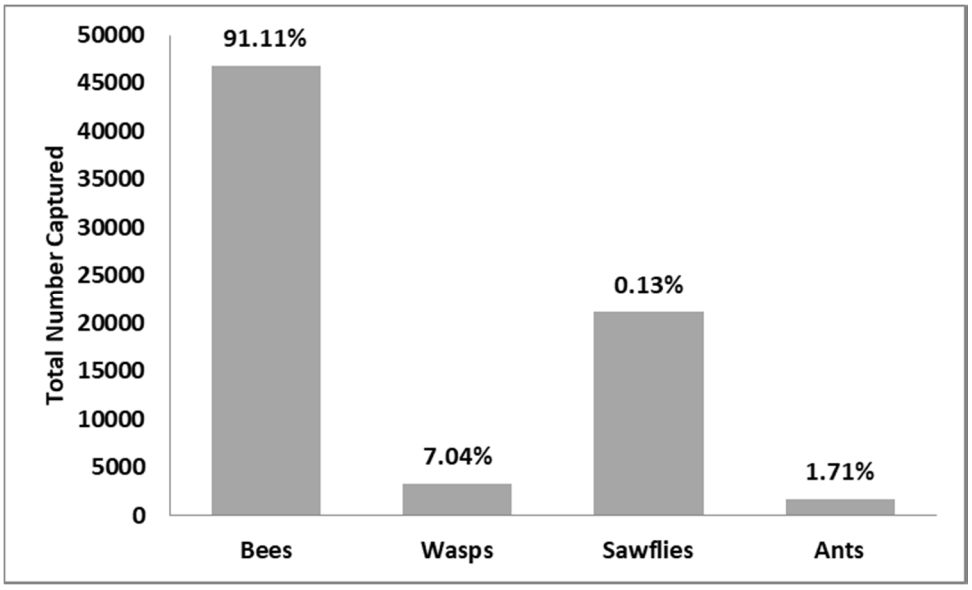



Figure II.3. Percentage of Hymenoptera groups (N = 46,846) collected in 2013–2014 with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

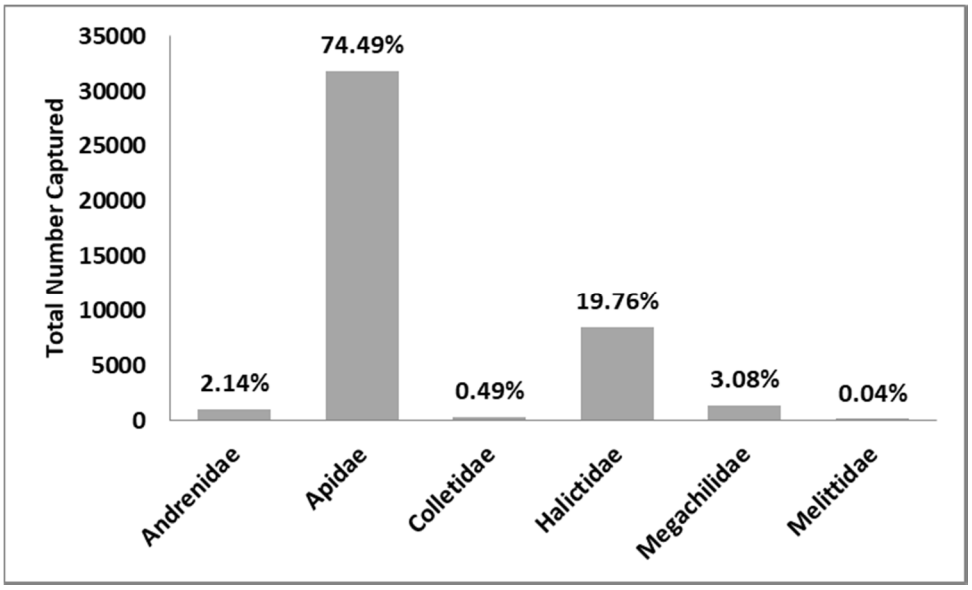



Figure II.4. Composition of melittofauna (N = 42,614) by Family collected in 2013–2104 with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

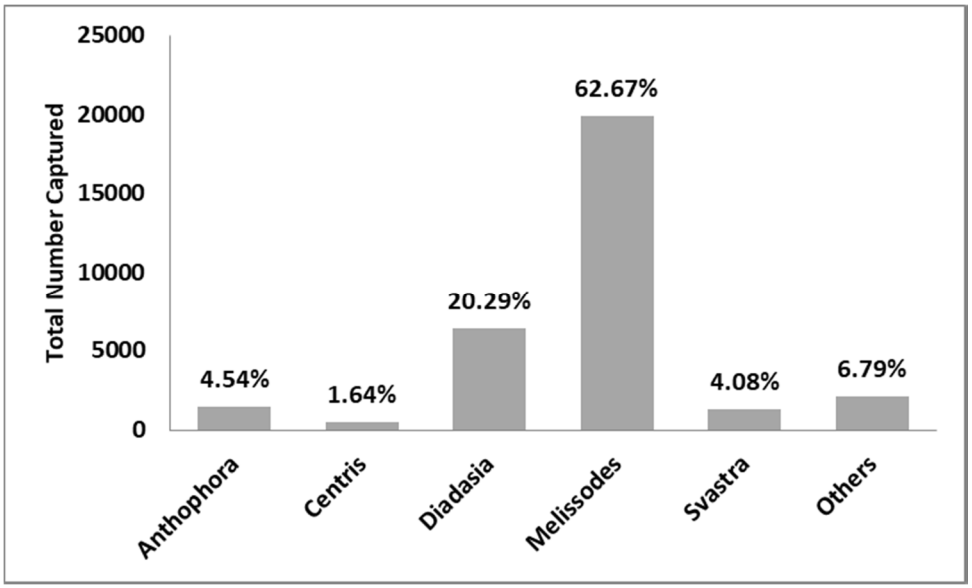



Figure II.5. Composition of Apidae (N = 31,788) by Genus collected in 2013– 2014 with combined methods (vane trap and insect net) in the Southern High Plains of Texas.

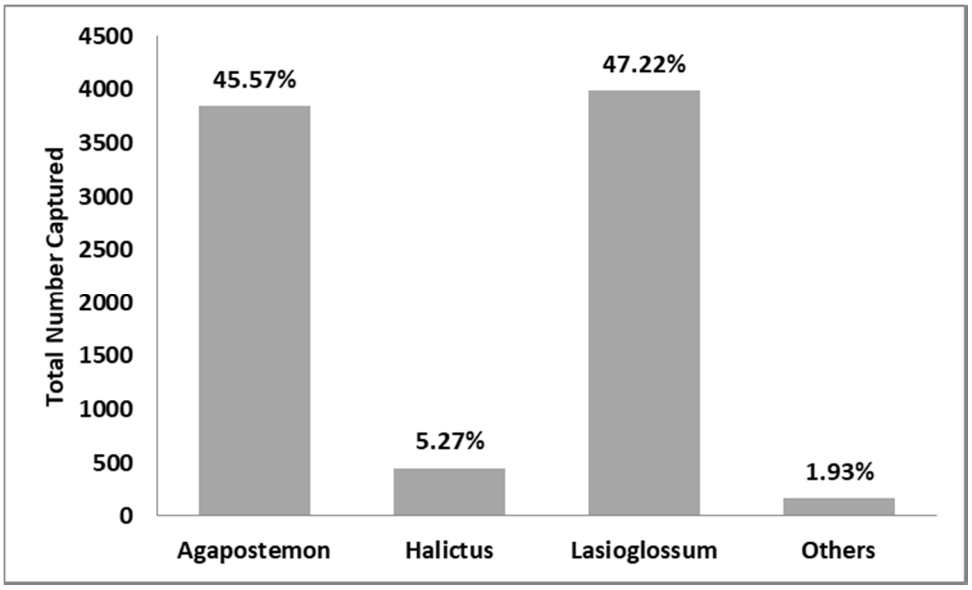



Figure II.6. Composition of Halictidae (N = 8,432) by Genus collected in 2013–2014 with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

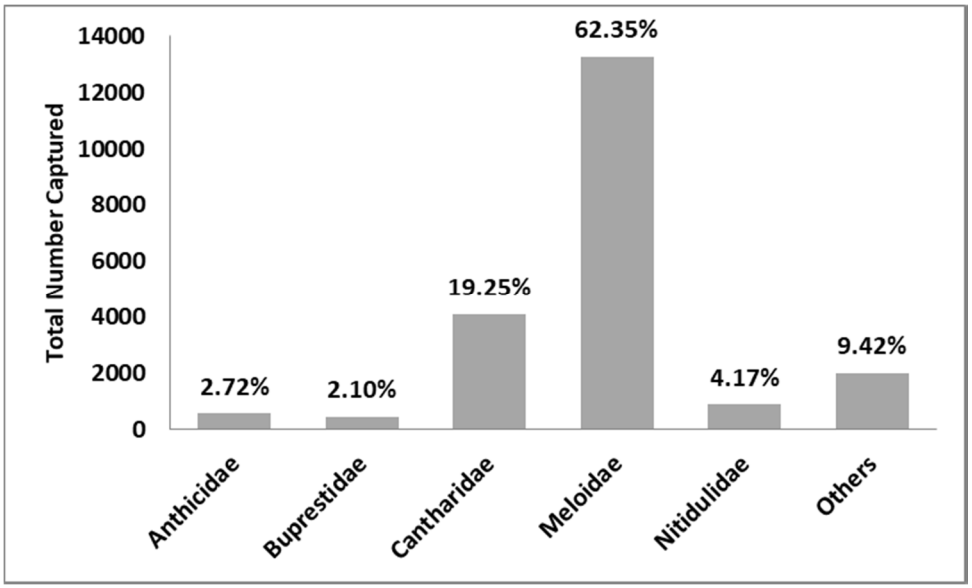



Figure II.7. Composition of Coleoptera (N = 21,235) by Family collected in 2013 – 2014 with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

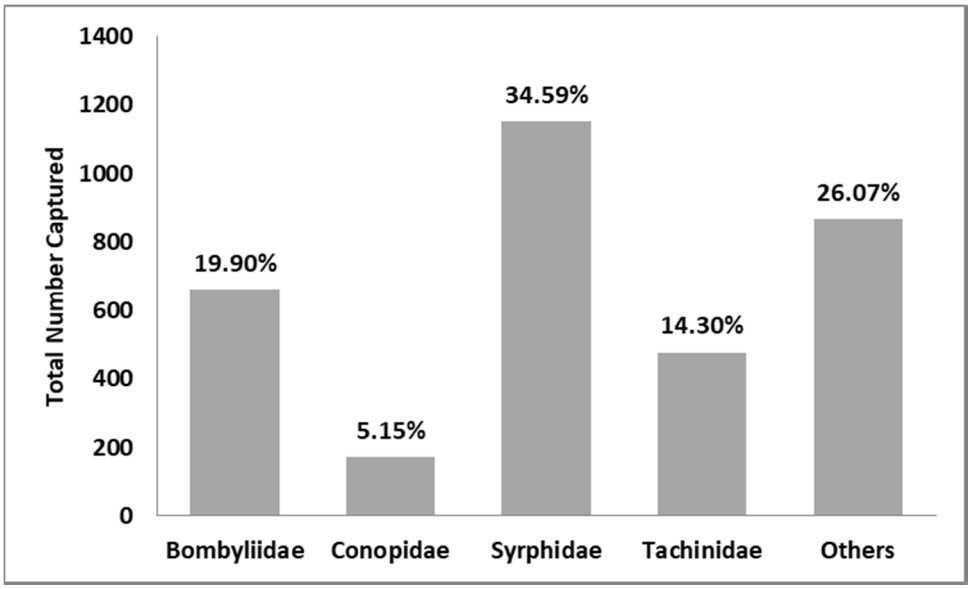



Figure II.8. Composition of Diptera (N = 3,322) by family collected in 2013 – 2014 with combined capture methods (vane trap and insect net) in the Southern High Plains of Texas.

# CHAPTER III

## INFLUENCE OF THE CONSERVATION RESERVE PROGRAM (CRP) AND PLAYA WETLANDS ON POLLINATOR COMMUNITIES IN THE SOUTHERN HIGH PLAINS


### ABSTRACT

Numerous studies have documented that invertebrate pollinator services are critical to the world economy. Factors including habitat degradation, agricultural practices, invasive exotic plant species, competition and disease from managed bees and climate change, however, threaten these pollinator populations. Several counties in West Texas and the Texas Panhandle were identified as at risk for a shortage of pollination service from wild bees due to declining bee populations and increasing demand for crop pollination. This region also has one of the highest concentrations of Conservation Reserve Program (CRP) contracts in the country. The CRP is the largest, voluntary, private lands conservation program in the United States and was targeted as a program to increase and improve pollinator habitat. Our objective was to determine how the predominant land uses in the Southern High Plains of Texas (SHP) (native grassland, CRP, and cropland) affect invertebrate pollinator abundance, species richness, and diversity and more specifically if the CRP can provide quality habitat for pollinators in the High Plains. We also examined how playa wetlands embedded within these land uses contribute to

pollinator habitat (land type: uplands vs. wetland). We used blue vane traps placed in the playa basins and adjacent uplands, and sweep netting pollinators feeding on flowers in each land use to determine pollinator diversity, richness, and composition. We analyzed total potential pollinators captured and separated them for analysis by order. Blue vane trap and sweep netting showed that CRP had consistently lower abundance, overall species richness and diversity than native grasslands and cropland, which were similar. With blue van traps, when land type was a significant effect, uplands had higher abundance, richness, and diversity than playas except for coleopterans. Coleoptera species were more abundant in playas than uplands during late season sampling periods. When measured with sweep netting, Coleoptera had higher overall diversity in uplands than playas. Although not statistically significant, total pollinator abundance and species richness, Hymenoptera abundance and species richness, and Diptera species richness in playas were higher than uplands after July. The years sampled in this study were during a severe extended drought; therefore, these results may be reflective of poor floral resources. The CRP has potential to create valuable habitat for pollinators if a diversity of native grasses and native forbs are incorporated into plantings to enhance pollinator foraging and nesting habitat. Replacing non-native grasses in the uplands will preserve playa hydrological function maintaining floral resources critical for pollinator diets later in the growing season. Further research regarding vegetation composition of buffer strips around playas should be pursued as another potential source of pollinator habitat.

## INTRODUCTION

The functional importance and monetary value of insect pollination services to the world economy cannot be understated. Economic estimates vary because of the lack of

distinction between managed and wild services (Allsopp et al. 2008) and because of different valuation metrics (Gallai et al. 2009). Gallai et al. (2008) determined that in 2005, the value of insect pollination to world agriculture was € 153 billion. In the United States in 2009, crops directly dependent upon insect pollination (apples, almonds, blueberries, cherries, cucurbits, oranges, and vegetable and legume seeds) (Abrol 2012) were valued at $ 15.12 billion. In 2004, crops and products that are indirectly dependent upon insect pollination (legume and vegetable seeds and milk and beef) (Abrol 2012) were valued at $ 12 billion and trending upward (Calderone 2012b).

There have been many cases of pollination service shortages (Kevan and Phillips 2001) such as the projected shortage in the United States suggested by Koh et al. (2016) (Figure III.1). In the 1990s, scientists became aware that many species of native invertebrate pollinators were in long-term decline, or their services were scarce (Allen-Wardell et al. 1998, Steffan-Dewenter et al. 2005, Biesmeijer et al. 2006, Council 2007, Gallai et al. 2009, Potts et al. 2010). Potential causes for this decline come from a combination of factors including habitat degradation and destruction (Cane and Tepedino 2001, Potts et al. 2010, Hadley and Betts 2012), habitat fragmentation (Cane and Tepedino 2001, Potts et al. 2010, Hadley and Betts 2012), agricultural practices (Cane and Tepedino 2001, Ghazoul 2005), and invasive exotic plant species (Hadley and Betts 2012, Vanbergen and Initiative 2013). Additional causes are climate change (Potts et al. 2010, Vanbergen and Initiative 2013), and competition and disease from managed bees (Thomson 2006, Szabo et al. 2012, Graystock et al. 2013). The issue reached a critical status in 2006 when beekeepers in the United States began reporting massive die-offs of honeybees (*Apis mellifera*) (Stokstad 2007, EPA 2017).

Although birds, bats, and abiotic factors such as wind and water contribute to pollination (Free 1993, Willmer 2011a, Abrol 2012), invertebrates provide the bulk of pollination (Proctor 1996, Kevan and Phillips 2001, Abrol 2012, Calderone 2012b). However, what defines an invertebrate pollinator varies according to climate and habitat (Kevan and Phillips 2001, Willmer 2011a, Ballantyne et al. 2015). Most are members of four insect orders (Willmer 2011a, Abrol 2012, Rader et al. 2016): Hymenoptera (ants, bees, wasps), Coleoptera (beetles) (Bernhardt 2000, Graham et al. 2012), Diptera (flies) (Larson et al. 2001, Clement et al. 2007, Jauker and Wolters 2008, Saeed et al. 2008, Inouye et al. 2015, Orford et al. 2015), and Lepidoptera (butterflies and moths) (Willmer 2011e). In some habitats in North America, thrips (Order Thysanoptera) (Annand 1926, Danieli-Silva and Varassin 2013) may serve as pollinators for some plant species. However, their recognized role as a plant pest often supersedes their potential role as a pollinator (NCR, 2007). Although bees are recognized as the primary providers of pollination services (Kevan and Baker 1983, Willmer 2011a), insects from Diptera, Coleoptera, and Lepidoptera should not be dismissed until their role in an ecosystem is understood.

Animal-mediated pollination takes place in an angiosperm when a pollinator moves pollen from the anther of one flower to the stigma of another (Kevan 1999, Willmer 2011a). Not all floral visits result in pollination, and not all floral visitors are pollinators (Kevan 1999, Willmer 2011a). Anthophiles are flower visitors that obtain nutrition from flowers but do not facilitate pollination (Kevan 1999). We considered all floral visitors and anthophiles as potential pollinators, although most bees are accepted as true pollinators (Kevan and Baker 1983, Willmer 2011a). For simplicity, we will use the

term “pollinator” for all insects captured in our traps that may have served as pollinators in the study landscape.

The Southern High Plains (SHP) is one of the most intensively cultivated regions in the Western Hemisphere (Bolen et al. 1989). The original native upland habitat was shortgrass prairie, and that which has not been cultivated was grazed by livestock (Smith and Haukos 2002, Smith 2003), primarily beef cattle (National Agricultural Statistics Service 2016). The dominant native grass species were blue grama (*Bouteloua gracilis*) and buffalograss (*Bouteloua dactyloides*) (Coffey and Stevens 2012).

Johnson et al., (2012) determined that row crops made up almost 52% of the land base in the SHP. Major crops were cotton, wheat, and irrigated and dryland sorghum, and corn (National Agricultural Statistics Service 2016). Because of intensive agriculture and high erosion potential, the SHP receives considerable funding for USDA conservation programs, primarily through the Conservation Reserve Program (CRP). The CRP is the federal government’s largest land conservation program (Stubbs 2014). The purpose of CRP is to provide rental payments and cost-share assistance to producers in exchange for voluntarily taking highly erodible land out of production and replacing it with permanent vegetation cover (Stubbs 2014). Almost $2 billion was provided annually for landowners enrolled in CRP since 1985 (Stubbs 2014). Currently, over 9.63 million ha are enrolled in the United States, and the Southern High Plains in Texas has some of the highest concentrations of contracts in the country (Figure III.2) (Farm Service Agency 2017).

Early CRP contracts in the Texas High Plains consisted of mostly non-native grasses, and many of these plantings remain in the landscape (Berthelsen et al. 1989). A

1988 survey of NRCS personnel documented that the most common CRP cover types in this region were various combinations of weeping lovegrass (*Eragrostis curvula*), Old world bluestem (*Bothriochloa ischaemum*), Kleingrass (*Panicum coloratum*), blue grama, sideoats grama (*Bouteloua curtipendula*), green sprangletop (*Leptochloa dubia*), plains bristlegrass (*Setaria vulpiseta*), and buffalograss (*Bouteloua dactyloides*) (Berthelsen et al. 1989). No flowering forbs were in these mixtures. These non-native tall grasses (excluding native *Bouteloua* spp.) are detrimental to this landscape because they are denser than native shortgrass species and can inhibit inundation of playa wetlands (O'Connell et al. 2012). Additionally, these dense grasses have the potential to out-compete native flowers and reduce foraging resources for native pollinators.

In response to the pollination crisis, the White House released a Presidential Memorandum - Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators (The White House 2014). The Pollinator Research Action Plan: Report of the Pollinator Health Task Force (The White House 2016a) and National Strategy to Promote the Health of Honey Bees and Other Pollinators: Report of the Pollinator Health Task Force (The White House 2016b), identified the CRP as a focal program to enhance and expand more than 2.8 million hectares of private and public land for pollinator habitat. From these reports, the Farm Service Agency and Natural Resource Conservation Service are tasked with identifying and expanding CRP plantings beneficial to pollinators. The SHP of Texas has some of the highest concentrations of CRP in the country (Table III.2) (Farm Service Agency 2017), so it is important that this area is studied to determine how CRP affects pollinator abundance, species richness and diversity relative to other land uses.

Playa wetlands are the keystone ecosystem in the SHP (Haukos and Smith 1994). They are shallow, depressional, recharge wetlands characteristic of prairie and semi-arid habitats formed and maintained by wind, waves, and dissolution (Smith 2003). Playas are approximately 3% of the SHP land base, providing biodiversity refugia (Bolen et al. 1989, Haukos and Smith 1994, Smith and Haukos 2002). These wetlands are under threat from watershed erosion and rural and urban development (Smith 2003). Johnson et al., (2012) determined that 60% of original playas were lost from the SHP between 1970 and 2008 from erosion caused sedimentation fill and loss of visible depression. Playa wetlands are a source of diverse floral resources (Bolen et al. 1989, Haukos and Smith 1994, Smith and Haukos 2002), and as such, they may be an important source of forage for pollinators, especially during drought. Loss of playas to sedimentation and agricultural conversion has potential to isolate pollinators and plant populations by habitat fragmentation in an already heavily altered landscape.

Ecological diversity is one of the fundamental metrics used in ecology and one of the primary indices to measure ecosystem health (Magurran 1988). Research on the influence of biodiversity on ecosystem function, or specifically the role it plays in preserving ecosystem function, has resulted in differing theories. Ehrlich and Ehrlich's (1981) "rivet-popper hypothesis" postulates that species in a community are like rivets in an airplane; a loss of a few rivets (species) and the airplane (habitat) still functions, but eventually, continued loss of rivets (or species) will lead to structural collapse (Ehrlich 1983, Ehrlich and Walker 1998). Another, the redundancy hypothesis, states that as long as there are species representing each functional group within an ecosystem, ecosystem function will be preserved (Walker 1992). Moreover, the insurance hypothesis states that

higher biodiversity ensures that there will be enough species present in an ecosystem with similar niches so that in the event of the loss of one, another can resume its function (Risser, 1995; Yachi & Loreau, 1999).

Although ecological communities with low species richness do not indicate an unhealthy ecosystem or loss of ecosystem function (Grime 1997), using species richness or diversity to compare land use within the same ecosystem can provide insight into how land use influences an ecological community. For example, Vergara & Badano (2009) demonstrated that low environmental impact forest systems in Veracruz, Mexico, had higher pollinator species richness and diversity than high-impacted systems (mostly cleared). In Switzerland, Ecological Compensation Areas (ECA) provide a financial incentive to promote biodiversity in agricultural settings and have higher pollinator species richness and abundance than adjacent meadows (Albrecht et al. 2007). Seed set and quality for some flowers were slightly greater in ECA's than meadows (Albrecht et al. 2007). Higher pollinator species richness also increases pollination services and seed set in orchard and laboratory settings through redundancy and complementarity (Fontaine et al. 2006, Brittain et al. 2013, Kühsel and Blüthgen 2015). There is currently no documentation of how land use affects pollinator communities in the SHP. Species richness and diversity is a starting point to detect changes in these ecosystem functions. With the emphasis on pollinator habitat for USDA programs and the extensive CRP area in the SHP, it is imperative that we have a better understanding of how the CRP affects pollinator populations relative to native grasslands and cropland. Knowing how pollinator diversity in CRP compared to other land uses will provide guidance on how to spend conservation dollars most effectively.

Our first objective is to compare abundance, species richness, and diversity of wild invertebrate pollinator communities in the three primary land uses of the SHP: cropland, CRP, and native grasslands. Our second objective is to compare abundance, species richness, and diversity of wild invertebrate pollinator communities in playa wetlands embedded in the three primary land uses, and compare them with their uplands to determine the importance of playa wetlands to pollinators. Previous research documented that the three principal land uses in the SHP have distinct vegetation characteristics (O'Connell et al. 2012) that could result in different suitability to pollinators. We hypothesized that native grasslands and their playas would have the greatest abundance, richness, and diversity of pollinators, then CRP and croplands, respectively.

The native vegetation around grassland playas protects the wetland from sediment runoff, but does not inhibit inundation (O'Connell et al. 2012) and encourages germination of perennial plant species. Perennial vegetation, which dominates grassland playas and their catchments (O'Connell et al. 2012), is a requirement for many species of native pollinators (Delaplane 2000), especially for insects with high energy demands such as those with larger body mass (Corbet et al. 1995, Corbet 2000). Wetland and upland plant species cover is equally represented in native grasslands (O'Connell et al. 2012), and because the presence of both types of plants indicates greater forb composition than CRP or cropland sites, there is greater insurance that there will be blooming flowers present throughout the season upon which pollinators can forage. Undisturbed habitat and reduced vegetation density in native grassland playas and catchments (O'Connell et al. 2012) also encourage nesting for solitary bees (Delaplane 2000). The transition zone

between the playa and upland could have enough bare soil without inundation to serve as nesting habitat for ground-nesting bee species. Therefore, native grassland playas should have a higher diversity of pollinators than playas embedded in CRP sites and cropland. Native grassland playas and their catchments could serve as a source of pollinators in proximity to species-poor habitats, or habitats without adequate nesting habitat.

CRP playas and their catchments will likely have pollinator diversity that varies according to individual sites, influenced by the vegetation composition and structure. O'Connell et al. (2012) noted that CRP land does not resemble native grassland. In the SHP, CRP is predominantly upland grass species (Berthelsen et al. 1989), with 400% greater cover of non-native species than other land uses (O'Connell et al. 2012). These upland species are dense, and CRP playas have twice as much biomass as cropland and native grassland playas (O'Connell et al. 2012). This density protects the playa from sediment runoff, but it also limits inundation (O'Connell et al. 2012). Consequently, these playas are wet 56% less than other land uses, which reduce wetland-dependent and perennial species richness and cover (O'Connell et al., 2012, Tsai et al., 2012). Although reduced inundation compromised CRP playas, O'Connell et al. (2012) showed that plant species richness was similar to native grassland habitat, although a larger percentage is non-native grass species (Berthelsen et al., 1989). As such, pollinator diversity in CRP playas will likely be lower than native grassland playas. Total species richness may also be lower. The higher biomass (O'Connell et al. 2012) may also reduce habitat opportunities for some pollinators and inhibit nesting (Delaplane 2000) because of lack of access to bare soil.

We hypothesized that cropland playas should have the lowest pollinator diversity because they have the lowest plant richness (O'Connell et al. 2012). Tsai et al. (2012) determined that cropland playas have greater annual and exotic species cover, and fewer perennials than other land uses. O'Connell et al. (2012) had similar determinations with croplands having fewer species/ha, reduced cover of all plants except annuals (83% less perennial cover), and more exposed ground than other land uses. Although annuals are attractive to many pollinators, they are not the preferred food source because they are a lower source of energy than perennials (Kearns et al. 1998). The primary reason for these land use characteristics is bare, disturbed ground from cultivation results in soil runoff into playas during precipitation events, which reduces playa volume and shortens the hydroperiod (Tsai et al. 2007). The shortened hydroperiod does not allow for adequate perennial establishment, and as a result, there are likely fewer perennial seeds in cropland playa seed banks (Tsai et al. 2007, O'Connell et al. 2012). Because of the proximity of playas to their catchments and how strongly the actions on each habitat influences the other (O'Connell et al. 2012), it can be difficult to separate the difference in pollinator species richness. Playas will likely have increased floral diversity over the uplands in which they are embedded (Smith and Haukos 2002), and as a result, higher diversity and species richness of pollinators when flowers are present and in bloom.

Our final objective is to provide recommendations for further research and guidance on how land managers can enhance the CRP for pollination services.

## MATERIALS AND METHODS

### *Study Location and Site Selection*

The nine-county area targeted in this study (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher) (Figure III.3) encompasses approximately 2,353,522 ha (U.S. Census United States Census Bureau 2007). The climate is dry steppe (Smith 2003). The mean daily temperatures from April - September in Amarillo, TX, the northern portion of the sampling area, was 13.50°C – 20.83°C, and average precipitation for April – September was 5.33 cm – 4.88 cm (National Weather Service 2017a). Lubbock, TX is in the southern portion of the sampling area and April – September temperature ranges from 15.83°C – 22.06°C, and average precipitation for April – September was 3.58 cm – 6.38 cm (National Weather Service 2017b). Precipitation comes primarily from thunderstorms in May – June, and September - October and can be highly variable (Smith 2003). When sampling began in April 2013, the area was in moderate to exceptional drought (The National Drought Mitigation Center 2017). At the end of September, several significant rain events toward the end of the season eased drought conditions, and only a small portion of the area was in extreme drought with the remaining moderate to severe (The National Drought Mitigation Center 2017). Extended dry conditions persisted into 2014, and at the start of the field season in 2014, Carson and Floyd Counties were in exceptional drought status, Bailey County was in severe, and the remaining counties were in extreme drought (The National Drought Mitigation National Drought Mitigation Center 2017). At the conclusion of 2014, Bailey County was abnormally dry, most of the sampling area was in severe drought, and a portion of Carson and Briscoe Counties in extreme drought (The National Drought Mitigation Center 2017). These conditions maintained a drought trend that started in March 2011 (National Drought Mitigation Center 2017).

In 2014, producers in the nine-county study area planted 809,978 ha in cotton, winter wheat, corn, sorghum, sunflowers, or soybeans (National Agricultural Statistics Service 2016) and cattle grazed most uncultivated areas. In 1992, playa area within the study site was estimated at 68,742 ha (Haukos and Smith 1994). In 2014, 292,564 ha in the study area were under CRP contract with over $ 25,624,627 in rental payments for the fiscal year (Farm Service Agency 2017).

In each county, we selected three playas with each land use represented; cropland, CRP land, and native grasslands. The selection was based on the dominant land use in the respective playa watershed. We used sites from previous long-term playa research except for native grassland sites in Carson and Hockley Counties, a CRP site in Castro County, and cropland site in Bailey County. We were able to find substitutes in each county except for the native grassland site in Carson County. Here, we used a reference site in adjacent Gray County to maintain similar abiotic environmental factors among treatments. Native grassland playas and their catchments represented the reference state of the landscape and had not been plowed or restored. Cropland was the land use state to which native landscapes were converted, and CRP was primarily exotic grasses. Each watershed location had an embedded playa, for 27 sampling sites total. This region is ideal for a study on how conservation programs affect pollinator diversity as it has one of the highest concentrations of CRP enrollment in the country (Figure III.2) (Farm Service Agency 2017). Additionally, several counties in the study (Bailey, Floyd, Hockley, Lubbock, and Swisher) (Figure III.1), have been identified as “at-risk” counties because the predicted supply of wild bees is less than what will be required to meet the demand for pollinator services (Koh et al. 2016).

*Methods*

We collected data from April – September in 2013 and 2014 for 26 weeks with 13 sampling periods (Table III.1). A bi-weekly rotation of sampling sites allowed us to capture weather differences and all blooming periods for flowers. Daily sampling occurred between 0800 and 1800. The three land uses in each county were sampled on the same day when weather and driving conditions permitted. We sampled by county to attempt to collect data under similar weather conditions at each location. We established six permanent sets of parallel vegetation belt transects, 25 m long by 2 m wide, three sets in the catchment and three sets in the playa. To establish transect locations, we trisected each playa from the center. With a random number generator, we selected a random azimuth bearing in each section, (1°-120°, 121°-240°, 241°-360°) and placed the transect on that bearing. We positioned upland transects similarly with the starting point approximately 25 m from the playa edge.

We collected pollinators with Springstar™ blue vane traps (Stephen and Rao 2005, 2007, Kimoto et al. 2012a, Rao and Ostroverkhova 2015). They are a visual attractant, not baited, and contain no killing agents or additives such as water and soap (Stephen and Rao 2005). Halfway down each transect (12.5 m), we placed a 1.25 m wooden post with a wire to hang a trap with six traps at each site, three in the playa, and three in the uplands. Each site representing each land use had two sampling units determined by land type; an upland sample and a playa sample, each consisting of the respective three trap contents pooled (Figure III.4). In each county, we had a cropland upland sampling unit, CRP upland sampling unit, native grassland upland unit, cropland playa sampling unit, CRP playa sampling unit, and native grassland playa sampling unit.

We adjusted the wire height so the traps hang in line with the height of the surrounding vegetation. Traps were set out each day and collected the following day as close to 24 hours as possible. We recorded the time traps were in the field within 15-minute intervals. We scheduled county collections so that we minimized driving distance between sites to accommodate trap collection before we sampled the next location. We killed specimens in the field by transferring the contents of the traps into a mesh vegetable bag and then placed the bag in a killing jar soaked with 99% ethyl acetate. Invertebrates collected from traps were stored in a Whirl-Pak collection bag representing each trap for that sampling period. We labeled each bag with the date, locality, and transect identification. Insects were stored in freezers before transport to Oklahoma State University or shipment to the United States Geological Survey Northern Prairie Wildlife Research Center (USGS NPWRC). We confirmed insect identification by consulting reference collections built with input from taxonomic specialists (Chapter II).

We also collected pollinators through targeted netting. We used 30.5 cm diameter sweep nets to capture insects. On the 25 x 2 m transect belt parallel to the one supporting the blue vane trap, we walked the transect, scanning for pollinators feeding on flowering forbs for six minutes. When found, the technician captured the insect, stored it in a Whirl-Pak bag, and documented the flower on which it was feeding. At this point, we stopped the timer until scanning for insects resumed. These data gave information on the diet of pollinators and more detailed evidence of the land use and land type in which they foraged. We recorded the plants that pollinators visited and compiled this information in a database of plant/pollinator linkages. Flowering forbs were identified in the field using field guides specific to the environment (Kirkpatrick 1992, Haukos and Smith 1997). Off

transect, we located a specimen of each plant insects fed on and pressed and preserved it for a reference collection. Oklahoma State University botanists identified any plants not recognized in the field. Insects were frozen and shipped to USGS NPWRC for identification, along with the plant database, for inclusion in the USGS Pollinator Library (USGS Northern Prairie Wildlife Research Center 2017).

*Statistical Analysis*

A three-way analysis of covariance (ANCOVA) was conducted on trap data to determine potential effects of sampling period, land use (native grassland [NG], Conservation Reserve Program [CRP], and cropland [AG]) land type (upland and playa) and interactions on invertebrate pollinator abundance, species richness, and Shannon-Wiener diversity. Hours traps were in the field were the covariate. The goal was to keep traps in the field as close to 24 hours as possible to capture pollinators active at different times of the day. Duration ranged from 6 hours to 46 hours with a mean of 22 hours. Extremes were due to traps being removed because of agricultural operations or because of inability to access sites due to weather. Land use, land type, and sampling period were fixed variables, and county and year were random variables. We ran ANCOVAs for total pollinators and then ran ANCOVAs for Hymenoptera, Diptera, Coleoptera, and Lepidoptera. We used Tukey's post hoc analysis to determine differences between means ($p < 0.05$). We used Minitab 17 (Minitab 17 Statistical Software 2010) to perform ANCOVAs and Tukey's post hoc analyses.

A three-way analysis of variance (ANOVA) was conducted on net data to determine effects of sampling period, land use [(native grassland (NG), Conservation

Reserve Program (CRP), and cropland (AG)], and land type (upland and playa) on invertebrate pollinator abundance, species richness, and Shannon-Wiener diversity. Land use, land type, and sampling period were fixed variables, and county and year were random variables. We ran ANOVAs for total pollinators then ran ANOVAs for Hymenoptera, Diptera, Coleoptera, and Lepidoptera. *Apis mellifera* were not a target species in this study. However, their presence was documented when discovered feeding on flowers. These specimens were not captured, and when they were accidentally captured, they were released. We used Tukey's post hoc analysis to determine differences between means following a significant ANOVA.

## RESULTS

### *Abundance- Blue Vane Traps*

The number of hours the traps were in the field (covariate) was significant for total pollinators, Hymenoptera, and Coleoptera abundance analyses (Table III.2). There was an interaction of sampling period and land use for total pollinator abundance (Table III.2). Therefore, we tested land use effects within each sampling period. Cropland ($\overline{X}$ = 74.9, SD = 203.5) had higher total abundance during period 13 than CRP ($\overline{X}$ = 55.28, SD = 56.46) and native grasslands ($\overline{X}$ = 50.47, SD = 51.18), [$F(2,100) = 11.17$, $p < 0.0001$] (Figure III.5a). There was an effect of land type and an interaction between sampling period and land use on hymenopteran abundance (Table III.2). Uplands ($\overline{X}$ = 39.44, SD = 65.80) had higher hymenopteran abundance than playas ($\overline{X}$ = 29.94, SD = 43.73), [$F(1, 1244) = 10.35$, $p = 0.001$]. Native grasslands ($\overline{X}$ = 29.94, SD = 43.73) had higher abundance during the fifth sampling period than CRP ($\overline{X}$ = 29.94, SD = 43.73) and

cropland ($\overline{X}$ = 29.94, SD = 43.73), [F (2, 88) =4.54, p=0.013] (Figure III.5b). Sampling period and land use were significant for dipteran abundance (Table III.2). Periods 2 and 13 had higher dipteran abundance than periods 5-12 (Figure III.5c). Dipteran abundance in cropland was higher than CRP and native grasslands (Figure III.5d). There was an interaction between sampling period and land use and sampling period and land type for Coleoptera (Table III.2). Cropland ($\overline{X}$ = 89.2, SD = 152.6), had higher abundance than CRP ($\overline{X}$ = 22.33, SD = 42.21) and native grassland ($\overline{X}$ = 20.42, SD = 38.76), [F (2, 90) = 6.93, p = 0.002] in sampling period 13 (Figure III.5e). Abundance in playas period 2 ($\overline{X}$ = 5.30, SD = 9.94) was higher than periods 7 ($\overline{X}$ = 1.35, SD = 3.82), 10 ($\overline{X}$ = 1.24, SD = 2.77), 9 ($\overline{X}$ = 1.13, SD = 2.27), 6 ($\overline{X}$ = 1.04, SD = 2.15), and 11 ($\overline{X}$ = 0.83, SD = 1.53), [F (12, 643) = 3.51, p < 0.000]. Abundance in uplands period 2 ($\overline{X}$ = 6.20, SD = 9.89) was higher than periods 7 ($\overline{X}$ = 1.54, SD = 4.56), 8 ($\overline{X}$ = 1.50, SD = 2.85), 9 ($\overline{X}$ = 1.19, SD = 3.28), 6 ($\overline{X}$ = 1.08, SD = 1.91), 10 ($\overline{X}$ = 0.96, SD = 1.58), and 11 ($\overline{X}$ = 0.83, SD = 1.15), [F (12, 643) = 3.71, p < 0.000] (Figure III.5f). There was an interaction between sampling period and land use for Lepidoptera (Table III.2). Abundance in cropland ($\overline{X}$ = 9.00, SD = 10.61) was higher than CRP ($\overline{X}$ = 3.94, SD = 4.97) and native grassland ($\overline{X}$ = 2.36, SD = 3.46), [F (2, 90) = 4.54, p < 0.0001] in sampling period 13 (Figure III.5g).

*Species Richness- Blue Vane Traps*

The number of hours the traps were in the field (covariate) was significant for total, Hymenoptera, Diptera, and Coleoptera richness (Table III.3). There were sampling period, land use, and land type effects on total species richness (Table III.3). Sampling periods 5 and 13 had higher richness than all sampling periods but 12 (Figure III.5a).

Cropland and native grassland were more species-rich than CRP (Figure III.6b), and uplands ($\overline{X}$ = 13.16, SD = 8.02) were more species-rich than playas ($\overline{X}$ = 11.36, SD = 8.33), [F (1, 1244) =19.09, p < 0.000]. Hymenoptera richness differed among sampling periods, land uses, and land type (Table III.3). Sampling period 5 was more species-rich than all periods except 13 (Figure III.6c). Cropland and native grassland had higher richness than CRP (Figure III.5d), and uplands ($\overline{X}$ = 9.04, SD = 5.83) were more species-rich than playas ($\overline{X}$ = 7.61, SD = 5.58), [F (1, 1244) = 23.08, p < 0.000]. There were sampling period and land use effects of dipteran richness (Table III.3). Periods 2 and 13 were more species-rich than all sampling periods but period 1 (Figure III.6e). Cropland had higher dipteran richness than CRP and native grasslands (Figure III.6f). There were land type effects and an interaction between sampling period and land use for Coleoptera (Table III.3). Uplands ($\overline{X}$ = 2.06, SD = 2.03) had higher richness than playas ($\overline{X}$ = 1.81, SD = 1.92), [F (1, 1244) = 16.49, p = 0.006]. We tested land use effect in each sampling period. Native grasslands ($\overline{X}$ = 3.91, SD=3.24) were more species-rich than cropland ($\overline{X}$ = 2.15, SD = 1.97) and CRP ($\overline{X}$ = 2.14, SD = 2.31), [F (1, 1244) = 16.49, p = 0.006] in period 5 (Figure III.6g). Sampling period and land use influenced Lepidoptera richness (Table III.3). Sampling period 13 had higher richness than all periods but 12 (Figure III.6h). Cropland lepidopteran richness was similar to native grassland but more rich than CRP (Figure III.i).

*Shannon-Wiener Diversity – Blue Vane Traps*

The number of hours the traps were in the field (covariate) was significant for total, Hymenoptera, and Coleoptera diversity (Table III.4). Sampling period, land use,

and land type influenced total diversity (Table III.4). Period 1 was less diverse than sampling periods 2 - 13 (Figure III.7a). Native grassland and cropland had the same Shannon diversity indices but were higher than CRP (Figure III.7b). Uplands ($\overline{X}$ = 1.83, SD = 0.69) were more diverse than playas ($\overline{X}$ = 1.68, SD = 0.73), [F (1, 1244) =16.49, p < 0.000].

Hymenoptera diversity differed among sampling periods, land types and land uses (Table III.4). All sampling periods were similar except period 1, which was less diverse (Figure III.7c). Cropland and native grassland were more diverse than CRP (Figure III.7d), and uplands ($\overline{X}$ = 1.59, SD = 0.68) were more diverse than playas ($\overline{X}$ = 1.39, SD = 0.73), [F (1, 1244) = 25.25, p < 0.000]. There were sampling period and land use effects on dipteran diversity (Table III.4). Period 2 was the most diverse period, and periods 6, 7, and 9-11 were the least diverse (Figure III.7e). Dipteran diversity was higher in cropland than CRP and native grasslands (Figure III.7f). There were land use effects and an interaction between sampling period and land type on Coleoptera diversity (Table III.4). Cropland and native grassland had higher coleopteran diversity than CRP (Figure III.7g). Abundance in playas periods 5 ($\overline{X}$ = 0.61, SD = 0.69), 12 ($\overline{X}$ = 0.57, SD = 0.48), 13 ($\overline{X}$ = 0.53, SD = 0.48), 11 ($\overline{X}$ = 0.53, SD = 0.51), 9 ($\overline{X}$ = 0.50, SD =0.51), 7 ($\overline{X}$ = 0.47, SD = 0.56), and 10 ($\overline{X}$ = 0.43, SD = 0.41) were higher than periods 2 ($\overline{X}$ = 0.09, SD = 0.28), 3 ($\overline{X}$ = 0.10, SD = 0.29), and 1 ($\overline{X}$ = 0.0, SD = 0.0), [F (12, 643) = 8.55, p < 0.000]. Abundance in uplands periods 7 ($\overline{X}$ = 0.77, SD = 0.58) and 5 ($\overline{X}$ = 0.70, SD = 0.69) was higher than periods 10 ($\overline{X}$ = 0.39, SD = 0.41), 4 ($\overline{X}$ = 0.35, SD = 0.50), 9 ($\overline{X}$ = 0.31, SD = 0.35), 3 ($\overline{X}$ = 0.17, SD = 0.36), 2 ($\overline{X}$ = 0.12, SD = 0.30), and 1 ($\overline{X}$ = 0.09, SD = 0.27), [F (12, 643) = 10.96, p < 0.000] (Figure III.7h). For lepidopterans, there was an interaction

of sampling period, land use, and land type (Table III.4). Cropland in sampling period 13 ($\overline{X}$ = 0.33, SD = 0.42) had a higher diversity of lepidopterans than sampling periods 11 ($\overline{X}$ = 0.16, SD = 0.36), 9 ($\overline{X}$ = 0.15, SD = 0.31), 10 ($\overline{X}$ = 0.09, SD = 0.27), 4 ($\overline{X}$ = 0.08, SD = 0.24), 2 ($\overline{X}$ = 0.08, SD = 0.24), 5 ($\overline{X}$ = 0.07, SD = 0.22), 3 ($\overline{X}$ = 0.07, SD = 0.21), 8 ($\overline{X}$ = 0.05, SD = 0.21), 6 ($\overline{X}$ = 0.04, SD = 0.16), 7 ($\overline{X}$ = 0.03, SD = 0.14) and 1 ($\overline{X}$ = 0.05, SD = 0.18) [$F(12,1244) = 11.52$, $p<0.0001$].

*Abundance- Sweep Netting*

There was an interaction of sampling period and land use and sampling period and land type on total pollinator abundance (Table III.5). Therefore, we tested land use and land type effects within each sampling period. Land use was significant in period 13. Cropland ($\overline{X}$ = 1.30, SD = 3.59) and native grasslands ($\overline{X}$ = 0.95, SD = 2.42) had higher abundance than CRP ($\overline{X}$ = 0.59, SD = 2.25), [$F(2,740) = 5.89$, $p = 0.003$] (Figure III.8a). Abundance in playas in period 12 ($\overline{X}$ = 3.85, SD = 5.51), [$F(1, 596) = 2.94$, $p < 0.000$] was higher than playas in all periods but 13. Abundance in uplands periods 13 ($\overline{X}$ = 2.55, SD = 4.34) and 12 ($\overline{X}$ = 2.43, SD = 4.18) were higher than periods 4 ($\overline{X}$ = 0.17, SD = 0.44), 2 ($\overline{X}$ = 0.26, SD = 1.21), 3 ($\overline{X}$ = 0.13, SD = 0.45), and 1 ($\overline{X}$ = 0.0, SD = 0.0), [$F(1, 596) = 10.96$, $p = 0.021$]. The majority of pollinator foraging shifted from uplands to playas in periods 10, 12 and 13 (Figure III.8b). For hymenopterans, there was an interaction of sampling period and land type (Table III.5). We tested for land type effects within each sampling period. Sampling period was significant within the interaction. Uplands in sampling period 8 ($\overline{X}$ = 1.00, SD = 2.64) had higher abundance than uplands in periods 2 ($\overline{X}$ = 0.08, SD = 0.45), 3 ($\overline{X}$ = 0.04, SD = 0.21), and 1 ($\overline{X}$ = 0.0, SD = 0.0).

Playas in sampling period 13 ($\overline{X}$ = 0.96, SD = 2.56) had higher abundance than playas in periods 4 ($\overline{X}$ = 0.02, SD = 0.15), 5 ($\overline{X}$ = 0.03, SD = 0.16, 2 ($\overline{X}$ = 0.06, SD = 0.41), 3 ($\overline{X}$ = 0.02, SD = 0.15), and 1 ($\overline{X}$ = 0.02, SD = 0.16), [F (12, 1149) = 2.02, p = 0.020]. Visitation shifted from upland to playas in period 10 (Figure III.8c). Cropland and native grassland had higher hymenopteran abundance than CRP (Figure III.8d). For Diptera, there was an interaction between sampling period and land use and sampling period and land type (Table III.5). Sampling period was significant in both interactions. Dipteran abundance in CRP in period 7 ($\overline{X}$ = 1.06, SD = 3.02) was higher than CRP in periods 3 ($\overline{X}$ = 0.0, SD = 0.0), 2 ($\overline{X}$ = 0.0, SD = 0.0), and 1($\overline{X}$ = 0.96, SD = 2.27), [F (12, 1153) =1.18, p = 0.033] (Figure III.8e). Playas in sampling period 10 ($\overline{X}$ = 0.0, SD = 0.0) had higher dipteran abundance than playas in periods 6 ($\overline{X}$ = 0.13, SD = 0.39), 2 ($\overline{X}$ = 0.04, SD = 0.29), 3 ($\overline{X}$ = 0.02, SD = 0.15), 4 ($\overline{X}$ = 0.0, SD = 0.0) and 1($\overline{X}$ = 0.0, SD = 0.0), [F (24, 1153) = 2.15, p = 0.001] (Figure III.8f). There was an interaction between sampling period and land use for coleopterans (Table III.5). Land use was significant in the interaction. Croplands ($\overline{X}$ = 2.62, SD = 4.87) and native grasslands ($\overline{X}$ = 1.31, SD = 2.88) had higher abundance in period 12 than CRP ($\overline{X}$ = 0.56, SD = 2.06), [F (2, 94) = 3.69, p = 0.031] (Figure III.8g). Sampling period influenced lepidopteran abundance (Table III.5). Period 8 had higher abundance than periods 1-7 and 10 (Figure III.8h).

*Species Richness- Sweep Netting*

There was an interaction between sampling period and land use, and an interaction between sampling period and land type on total richness (Table III.6). We tested land use and land type effects within each sampling period. Cropland had more

species in period 13 ($\overline{X}$ = 2.68, SD = 3.21) than native grasslands ($\overline{X}$ = 0.56, SD = 2.06) and CRP ($\overline{X}$ = 0.78, SD = 1.79), [F (2, 94) = 7.23, p = 0.001] (Figure III.9a). Playas were more species rich in sampling period 13($\overline{X}$ = 1.72, SD = 2.80) and 12 ($\overline{X}$ = 1.72, SD = 2.00) than periods 7 ($\overline{X}$ = 0.63, SD = 0.88), 9 ($\overline{X}$ = 0.51, SD = 0.68), 6 ($\overline{X}$ = 0.38, SD = 0.88), and 5 ($\overline{X}$ = 0.14, SD = 0.35). Uplands were more species rich in sampling period 7 ($\overline{X}$ = 1.15, SD = 1.52) than periods 3 ($\overline{X}$ = 0.11, SD = 0.38) and 1 ($\overline{X}$ = 0.0, SD = 0.0), [F (12, 1149) =1.89, p = 0.032] (Figure III.9b).

There was a land use effect and an interaction between sampling period and land type for Hymenoptera (Table III.6). Cropland and native grassland hymenopteran richness were statistically similar. Native grassland and CRP species richness was also similar, but cropland was more species-rich than CRP (Figure III.9c). Playas in sampling period 13 ($\overline{X}$ = 0.74, SD = 1.77) were more species rich than playas is sampling periods 7 ($\overline{X}$ = 0.22, SD = 0.54), 6 ($\overline{X}$ = 0.08, SD = 0.33), 2 ($\overline{X}$ = 0.04, SD = 0.29) and 1 ($\overline{X}$ = 0.02, SD = 0.16). Uplands in sampling periods 7 ($\overline{X}$ = 0.59, SD = 0.96) were more species rich than periods 2 ($\overline{X}$ = 0.08, SD = 0.45), 3 ($\overline{X}$ = 0.04, SD = 0.21), and 1 ($\overline{X}$ = 0.0, SD = 0.0), [F (12, 1149) = 2.19, p = 0.010] (Figure III.9d). There were interactions between sampling period and land use and sampling period and land type for dipterans (Table III.6). Cropland in period 13 ($\overline{X}$ = 0.79, SD = 1.49) was more species-rich than native grassland ($\overline{X}$ = 0.28, SD = 0.57) and CRP ($\overline{X}$ = 0.08, SD = 0.37), [F (2, 94) = 5.04, p = 0.008] (Figure III.9e). Playas in sampling period 13 ($\overline{X}$ = 0.53, SD = 1.27) were more species-rich than playas in periods 6 ($\overline{X}$ = 0.11, SD = 0.32), 5 ($\overline{X}$ = 0.05, SD = 0.23), 2 ($\overline{X}$ = 0.04, SD = 0.29), 3 ($\overline{X}$ = 0.02, SD = 0.15), and 1 ($\overline{X}$ = 0.0, SD = 0.0), [F (12, 1149) = 1.77, p = 0.049] (Figure III.9f). There was an interaction between sampling period and

land use for coleopterans (Table III.6). Cropland ($\overline{X}$ = 0.79, SD = 1.49) and native grassland ($\overline{X}$ = 0.28, SD = 0.57) had higher richness than CRP in period 12 ($\overline{X}$ = 0.08, SD = 0.37), [F (2, 94) = 3.92, p = 0.023] (Figure III.9g). There was an effect of sampling period for lepidopterans (Table III.6). Sampling period 8 had higher richness than periods 1-7 and 10 (Figure III.9h).

*Shannon-Wiener Diversity – Sweep Netting*

There was an interaction between sampling period and land use for total pollinators (Table III.7). Cropland ($\overline{X}$ = 0.62, SD = 0.72) was more diverse in period 13 than native grassland ($\overline{X}$ = 0.26, SD = 0.44) and CRP ($\overline{X}$=0.18, SD=0.50), [F (2, 94) = 5.80, p = 0.004] (Figure III.10a).

Hymenoptera diversity differed among sampling periods (Table III.7). Sampling period 13 had higher diversity than periods 1-4 and 6 (Figure III.10b). There was an interaction of sampling period, land use and land type on dipteran diversity (Table III.7). We tested the interactions of sampling period and land use and sampling period and land type and both were significant. Croplands were more diverse in sampling period 13 ($\overline{X}$ = 0.15, SD = 0.42) than periods 2 ($\overline{X}$ = 0.02, SD = 0.12), 9 ($\overline{X}$ = 0.0, SD = 0.00), 1 ($\overline{X}$ = 0.0, SD = 0.0), 4 ($\overline{X}$ = 0.0, SD = 0.0), 3 ($\overline{X}$ = 0.0, SD = 0.0), and 12 ($\overline{X}$ = 0.0, SD = 0.0), [F (24, 1149) = 1.99, p = 0.003]. Playas were more diverse in sampling period 13 ($\overline{X}$ = 0.11, SD = 0.36) than periods 2 ($\overline{X}$ = 0.01, SD = 0.10), 5 ($\overline{X}$ = 0.0, SD = 0.0), 9 ($\overline{X}$ = 0.0, SD = 0.0), 1 ($\overline{X}$ = 0.0, SD = 0.0), 3 ($\overline{X}$ = 0.0, SD = 0.0), 4 ($\overline{X}$ = 0.0, SD = 0.0), and 6 ($\overline{X}$ = 0.0, SD = 0.0), [F (12, 1149) = 2.16, p = 0.012] (Figure III.10c). Sampling period, land use, and land type had an effect on coleopterans (Table III.7). Sampling period 12 had the

highest seasonal diversity of coleopterans (Figure III.10d). Cropland and native grassland had higher coleopteran diversity than CRP (Figure III.10e). Uplands ($\overline{X}$ = 0.035, SD = 0.158) were more diverse than playas ($\overline{X}$ = 0.019, SD = 0.113), [F (1, 1149) = 4.15, p = 0.042].

## DISCUSSION

### *Land use and land type effects*

Land use and land use history can have a profound effect on invertebrate pollinator abundance, richness and diversity (Carré et al. 2009, Garibaldi et al. 2011, Kennedy et al. 2013, Berglund et al. 2014, Vanbergen 2014, Vanbergen et al. 2014). However, because of environmental complexity, determining impacts is difficult (Dauber et al. 2010, Kennedy et al. 2013). Additionally, when trying to determine the effect of land use on an entire community of pollinators of multiple orders, many different life histories and habitat niches exist simultaneously complicating conclusions (Pisanty and Mandelik 2015).

### *Influence of sampling period*

Sampling period or season obviously influenced abundance, richness, and diversity. For vane trap data, there were sampling periods effects on total richness and diversity, hymenopteran richness and diversity, dipteran abundance, richness and diversity, and lepidopteran richness. With sweep net data, there was a sampling period effect on Hymenoptera and Coleoptera diversity and Lepidoptera abundance and richness. For many of the interactions between sampling period and land use and sampling period and land type, the early periods had smaller metrics than mid or late-

season periods. The influence of season is likely due to different life histories among orders (Larson et al. 2001, Marshall 2012, Pisanty and Mandelik 2015), and early season cold weather conditions (Linsley 1958, Romoser 1998, Willmer 2011a, Inouye et al. 2015). Other exogenous and endogenous factors that result in population fluctuations throughout the season include the amount of sunlight, major rain events during critical life stages such as nesting, strong wind, disease, parasites and predators (Linsley 1958, Triplehorn and Johnson 2005, Kremen et al. 2007).

*Uplands and Playas*

When there was a land type effect of abundance, richness, and diversity, uplands had higher values than playas for all comparisons except Coleoptera abundance for trap data. Coleoptera abundance was higher in playas during sampling period 13. Results from netting showed few land type effects, but when they were present, coleopterans were more diverse in uplands than playas, and playas had a higher abundance of dipterans during period 10. The higher means in uplands for both sampling methods is likely due to extended drought conditions that had persisted since 2011 (National Drought Mitigation Center 2017). Playas had been dry for several years, and for the first several months of both sampling seasons, basins had few wetland flowers on which pollinators could forage. Sparse emergent vegetation in some wetlands recently inundated after major precipitation events late in 2014 could also be a contributing factor to higher insect activity in the uplands. Approximately 70% of wild bees are solitary and ground nesters (Black et al. 2011), and most species cannot survive flooded conditions (Michener 2007). Consequently, in any season, there is little nesting habitat within the playa. High coleopteran abundance in playas during period 13 from trap data was likely due to masses

of *Chauliognathus* spp. and *Epicauta* spp. feeding on late-season blooms of *Polygonum pensylvanicum* and *Helianthus annuus* in some wetlands. It is difficult to determine if high dipteran abundance during period 10 was attributable to land type characteristics. However, many species of flies spend part of their life cycles as aquatic larvae (Romoser 1998, Triplehorn and Johnson 2005), so high abundance may have been an outcome of flooded conditions in some wetlands. Although not significant, sweep net results showed that total pollinator, hymenopteran and dipteran abundance and species richness were higher in playas than uplands after sampling period 9 (mid-July – late September). Increasing richness in playas could be a result of playa forbs blooming after wetland inundation earlier in the season. Playas may be critical for late season pollinator foraging when wetland forbs are more abundant.

*Cropland*

Agricultural conversion is correlated with the loss of biodiversity (Carvell et al. 2007, Carvell et al. 2011, Tscharntke et al. 2012, Kennedy et al. 2013, Bennett and Isaacs 2014, Chateil and Porcher 2015, De Palma et al. 2015), and it can change the fundamental structure of plant-pollinator networks (Vanbergen et al. 2014). Nonetheless, agricultural landscapes are not always lacking in diversity or abundance (Tylianakis et al. 2005, Winfree et al. 2007). In this study, cropland had high pollinator abundance, species richness, and diversity compared to CRP and was similar to, or often higher than, native grasslands based on trap and net data. There are species and communities of wild bees that are not harmed by intensive agriculture (Winfree et al. 2007, Cariveau et al. 2013, Mogren et al. 2016). Homogenization of the landscape, however, may result in a shift to more generalist or common bee species (Carré et al. 2009, Mogren et al. 2016).

Generalist species are more tolerant of disturbance associated with land use and not as prone to extinction as pollinators with more specialized resource needs (Weiner et al. 2014). Mogren et al. (2016) demonstrated that northern Great Plains agricultural landscapes had mostly degraded habitat outside of crop monocultures, including less intensively managed forage crops and wetlands, which resulted in a predominance of generalist species such as *Melissodes* spp. and halictid bees. Our results were similar in the SHP. We documented high abundance and richness of *Melissodes* spp. with 18 species, eight species of *Agapostemon* spp., and four species and one subgenus of *Lasioglossum* spp. (Chapter II). Although Melissodes was species-rich, most of the species share similar functional roles in the landscape feeding primarily on composites (Ascher 2016), a major portion of visits at our sampling sites (Chapter IV). These three genera represented just over half of the bees collected during our study (Chapter II). For this study, however, we did not determine the quality of shortgrass prairie as in the study of Mogren et al. (2016).

Many studies show how agricultural practices influence pollinator diversity (Bañkowska 1981, Kim et al. 2006, Gibson et al. 2007, Power et al. 2012, Chateil and Porcher 2015, Forrest et al. 2015, Basu et al. 2016). De Palma et al. (2015) determined that a change in land use and agricultural intensification alone does not explain the variation in abundance and presence of bees. It can be difficult to separate direct (food and nesting resources) and indirect effects (land use and landscape) on pollinator communities (Roulston and Goodell 2011). Additionally, varying ecological traits and life histories among bees confound pollinator community response to environmental disturbance (Winfree et al. 2009, Williams et al. 2010, De Palma et al. 2015, Forrest et al.

2015, Pisanty and Mandelik 2015). This variation in response makes it a challenge to detect distinct patterns that can be attributed to land use alone (Roulston and Goodell 2011, De Palma et al. 2015). A meta-analysis of the literature revealed that although there were land use differences that showed that pollinators responded negatively to human disturbance, the magnitude of effects was small in all circumstances except where little natural habitat remained (Winfree et al. 2009). Deguines et al. (2012) found that hymenopterans appear tolerant to different land uses. Our study complements these analyses in that differences between cropland and native grasslands were often small.

Roulston and Goodell (2011) argued that food resources were the primary direct factor that influenced bee populations. Vegetation data showed that croplands and native grasslands had higher floral cover than CRP in our study, and late season blooms after playa inundation produced the high floral abundance within the land uses (Chapter IV). Weedy flowers also play a critical role in maintaining pollinator populations in croplands (Carvalheiro et al. 2011). Many of our cropland sites were near ditches and unmaintained areas that supported populations of flowers that were outside of our sampling transects. Additionally, all but two of nine cropland playas were unplowed. This may have biased our results because of difference in types of habitat disturbance. O'Connell et al. (2012) sampled 174 cropland playas in their study, and 71 (41%) of those playas were unplowed. Our study had a higher percentage of unplowed cropland playas than what is found in the landscape. Producers treated the plowed croplands as part of the agricultural field and had crops planted within the wetland. With the unplowed cropland playas, there were two types of upland immediate from the crops. They either were surrounded by unmanaged

vegetated buffer strips, or had plowed but unplanted soil that may have provided food and nesting habitat for insects.

Riparian buffer strips have been shown to support richer populations of plants and higher numbers of pollinators than adjacent intensively managed grasslands (Cole et al. 2015), and in southwestern Minnesota, butterfly abundance and diversity was positively correlated with buffer strip width (Davros et al. 2006). Potts et al. (2003) observed that the loosely tilled soil of agricultural fields provided desirable nesting habitat for *Melissodes* spp. (Mogren et al. 2016) and halictids (Pisanty and Mandelik 2015, Mogren et al. 2016). However, (Roulston and Goodell 2011) found little evidence that nesting resources were limiting for bees. These de facto buffered areas around playas and the protected floral resources within the playas served as valuable habitat for pollinators for foraging and nesting resources primarily through abundant and consistent floral resources. Agricultural areas have potential to provide quality habitat for pollinators and should be included in conservation programs (Deguines et al. 2012) to expand pollinator habitat. In the SHP, cropland playas and their immediate uplands should be a focus of pollinator conservation.

Dipteran pollinators have a different response to landscape characteristics than hymenopterans. While adult and larval bees use nectar and pollen for survival (Michener 2007), larval and adult dipterans have varying resource requirements (Bañkowska 1980, Kearns 2001). Larval food source availability is more strongly linked to population fluctuations for many dipterans than floral abundance for adults (Bañkowska 1980, Kearns 2001, Schweiger et al. 2007, Meyer et al. 2009). These resource requirement differences can result in different habitat requirements for flies than bees (Power et al.

2012, Power et al. 2016). Similar to hymenopterans, different fly life histories may obscure variations in population response to disturbance (Kearns 2001) and can result in diverse responses to land use changes (Schweiger et al. 2007, Meyer et al. 2009). As with Hymenoptera, generalist dipteran species are minimally affected by land use changes (Schweiger et al. 2007). Non-syrphid dipteran populations are resilient to agricultural conversion and could be essential alternative pollinators where the service is limited by land use (Meyer et al. 2009)

When coleopteran abundance, richness and diversity are compared in croplands and CRP, the differences are small biologically. The differences, however, are likely due to higher floral cover in cropland than CRP (Chapter IV). Coleopterans are generalist pollinators and will frequently visit (Larson et al. 2001, Mawdsley 2003, Wilmer 2011b, Inouye et al. 2015, Orford et al. 2015) and feed on a variety of flowers (Kevan and Baker 1983, Larson et al. 2001, Abrol 2012). Many coleopteran families are considered anthophilous and could be significant pollinators in some ecosystems (Proctor 1996, Wilmer 2011b).

Croplands also had high lepidopteran abundance relative to CRP and native grasslands. The majority of specimens collected were from the family Noctuidae, the tribe Hadenini and *Feltia jaculifera* (Chapter II). Many noctuids are considered agricultural pests, some specialized to sorghum (Triplehorn and Johnson 2005). Hadenini are cutworms (Triplehorn and Johnson 2005), and *Feltia jaculifera* is a wheat pest (Eaton and Kaufman 2007). Our data were likely biased because light trapping (Infusino et al. 2017) and transect walks (Pollard 1977) are more appropriate methods for collecting lepidopterans.

*Native grassland*

We hypothesized that native grasslands would support higher richness and diversity of pollinators than CRP and croplands based on data from O'Connell et al. (2012). A high percentage of grassland cover in a landscape has been associated with supporting a higher diversity of pollinators (Bennett and Isaacs 2014, Pisanty and Mandelik 2015). Cropland and native grassland pollinator richness and diversity in our study area were similar, and cropland often had a higher abundance of pollinators than the other land uses. Previous studies have demonstrated that in order for grasslands to support a diverse pollinator community, they must have high floral diversity and abundance (Potts et al. 2003b, Dauber et al. 2010, Fründ et al. 2010, Blaauw and Isaacs 2014), and provide adequate nesting habitat (Black et al. 2011, Black et al. 2014). Level of disturbance and vegetation complexity also influence insect diversity (Kruess and Tscharntke 2002a).

Landowners in the SHP managed all native grassland sites in this study as grazing lands, and this likely played a role in influencing pollinator populations (Gibson and New 2007). Effect of grazing on pollinators is mixed, but there is evidence it changes the way pollinators select plants for visitation (Vázquez and Simberloff 2003, Vanbergen et al. 2014). Most research supports that grazing enhances bee and flower richness and diversity, with appropriate grazing intensity dependent upon the habitat (Vulliamy et al. 2006, Yoshihara et al. 2008, Wilkerson et al. 2013). Managed grazing can be used as a tool to enhance biodiversity (Darkoh 2003). Overgrazed (Darkoh 2003), heavily grazed (Vulliamy et al. 2006), and intensively managed grassland pastures (Kruess and Tscharntke 2002a, Cole et al. 2015), however, can result in poor floral resources and

corresponding low diversity of plants and pollinators (Darkoh 2003, Vulliamy et al. 2006, Cole et al. 2015). Exceptional drought conditions starting in 2011 and reduced forage because of lack of adequate regrowth of grass and forbs degraded native grassland sites in this study. The deteriorated condition of the habitat could have contributed to similar species richness and diversity measures of native grassland and cropland sites based on trap and net data.

When designing agricultural plans to enhance pollinator communities, it is accepted that semi-natural sites will harbor greater pollinator species than croplands (Morandin et al. 2007, Garibaldi et al. 2011, Kennedy et al. 2013, Smith et al. 2013, Pisanty and Mandelik 2015). Duflot et al. (2015) defined semi-natural habitats as relatively permanent aspects of an agricultural landscape that include pastures, hedgerows, and woodlands. Crops often have higher rates of pollination when they are near these natural areas than cropland in a homogenous landscape because natural areas serve as a source of higher abundance and richness of pollinators (Klein 2009, Vergara and Badano 2009, Carvalheiro et al. 2012, Boreux et al. 2013). Pollination may not increase, however, if the habitat quality of the natural areas is poor (Kennedy et al. 2013). Moreover, a high abundance of generalist pollinators in cropland can indicate a lack of habitat complexity across the landscape (Mogren et al. 2016) and reduced functional diversity (Schweiger et al. 2007). Pisanty et al. (2015) showed that pollinator species richness varied across a life history gradient from semi-natural areas into agricultural fields. Pollinators with more specialized life histories and higher environmental sensitivity were found closer to natural areas and generalists predominated cropland settings (Pisanty and Mandelik 2015). Because we did not detect strong differences in

species composition between native grassland and cropland, it is possible that native grasslands are poor to marginal quality pollinator habitat under the climate and grazing regimes found in this study.

Native grassland had the lowest dipteran abundance and species richness based on trap data. A study of turloughs, seasonal pools in limestone areas of Ireland, showed that dipteran abundance and richness were lowest in the most heavily grazed sites (Ryder et al. 2005). Similar to hymenopterans, specialist dipterans are dependent upon high-quality habitat, and more disturbed areas have primarily generalist species (Schweiger et al. 2007). Power et al. (2012) found that grasslands had high syrphid richness and diversity. This difference with our study is likely due to the effect of grazing. In many studies, habitat with active livestock grazing is considered agricultural land. In our study, our reference sites were grazed which may also explain some conflicting results between natural and agricultural areas.

Coleopteran response to land use was somewhat different from hymenopterans. Coleopterans had a positive association with cropland and natural areas (Deguines et al. 2012). In saltmarsh ecosystems in Europe, Ford et al. (2013) found that there was no difference in diversity between ungrazed and grazed plots. However, functional groups within assemblages changed. While we did not analyze coleopteran functional groups in this study, our results are similar to Deguines et al. (2012).

*CRP*

There is little information on how CRP affects pollinators. Most research has focused on game birds (Berthelsen et al. 1989, Matthews et al. 2012a, b, Blank 2013)

and grassland birds (Herkert 2007, Osborne and Sparling 2013). Pollinator habitat was included as one of the CRP Initiatives in 2012, and there were 2,225 ha enrolled nationwide in 2014 (Stubbs 2014). In this study, the CRP had consistently lower abundance, species richness, and diversity of pollinators compared to cropland and native grassland. All CRP sites in this study were seeded in a mix of grasses, primarily non-natives (Berthelsen et al. 1989) that were denser than native vegetation (O'Connell et al. 2012). These plantings likely resulted in a lack of floral foraging resources (Gilgert and Vaughan 2011, Roulston and Goodell 2011, Black et al. 2014) and suitable nesting sites (Gilgert and Vaughan 2011, Black et al. 2014).

In Europe, agri-environmental schemes (AES) are similar to the CRP in that farmers are provided payments to implement practices that enhance environmental quality. These practices have delivered variable results relative to pollinators (Carvell et al. 2007, Scheper et al. 2013). As might be expected, AES's have been most effective in intensively farmed areas and habitat-poor landscapes (Carvell et al. 2007, Pywell et al. 2011). Higher pollinator abundance and richness was likely because of the contrast between simple and complex habitats (Scheper et al. 2013). Studies have demonstrated that highly disturbed landscapes favor abundant, generalist species (Carré et al. 2009, Basu et al. 2016), and functional diversity is often low in agricultural landscapes (Forrest et al. 2015). Kleijn et al. (2006) determined that AES's had a slight positive effect on biodiversity, primarily through the increase in common species, as many rare or threatened species did not benefit (Kleijn et al. 2006). Scheper et al. (2013) recommended that when designing an AES seeding mixture, increasing pollinator biodiversity rather than just increasing pollination service should be a specific management objective.

Increasing the floral component of a seed mix without consideration of the variations in life histories and functional traits of a diverse community of pollinators may not increase pollinator biodiversity (Isaacs et al. 2009, Forrest et al. 2015, Pisanty and Mandelik 2015). Pollinators are part of a mutualism, and restoring native plants to a landscape is essential for establishing diverse pollination interactions (Menz et al. 2011).

In the SHP study area, *Melissodes* spp. and halictid species abundance was high (Chapter II). If a land manager adds only generalist and common flowers that are easy to establish, the seed mix will favor these generalist populations without creating habitat for rarer, specialist species. Wild bees in Andrenidae, Colletidae, Megachilidae, and Melittidae comprised 5.75% of our specimens (Chapter II). The life histories, floral requirements and habitat requirements of some of these less abundant families, as well as specialist species within Apidae and Halictidae should be considered (Chapter IV), and native plants adapted to the region to meet these needs could then be incorporated into seed mixes (Isaacs et al. 2009) to make CRP more valuable to pollinators.

*Conclusion*

The challenge in determining if a landscape has a diverse or species-rich community of pollinators at any point in time is having adequate data to document if there are increasing or decreasing trends in the population, especially in abundance (Michener 2007). North America has lacked an organized, long-term monitoring program for non-*Apis* wild bees, so a current status of most wild pollinators is unknown. However, most evidence points to declines (National Resource Council 2007). Extensive species counts are often limited to a few small areas that are well-known and frequently sampled

(Michener 2007). Additionally, it can be difficult to compare species richness among different habitats across the world because landscapes with a higher diversity of habitats and a more extensive range of vegetation, soil and topographic conditions are likely to harbor a more diverse assemblage of pollinators (Michener 2007, Tscharntke et al. 2012). For wild bees, the most abundant and species-rich areas are warm-temperate xeric regions, specifically the Mediterranean basin, Central Asia, and Madrean region of North America (Michener 2007). To date, the most species-dense location is likely Pinnacles National Park of central California, a mix of chaparral, oak woodlands and canyon bottoms in a semi-arid Mediterranean climate (Messinger and Griswold 2003, Meiners 2016). Meiners (2016) identified 479 bee species there. Studies in the Madrean states of Northern Mexico documented 396 species in Chihuahua, 359 species in Sonora, and 445 species in Baja (Ayala et al. 1996, Michener 2007). Tscheulin et al. (2011) collected 340 species by net in olive orchards in 2004 on Lesvos Island, Greece, a Mediterranean climate. A similar study in Greece resulted in 267 species from 36 genera collected in olive orchards and phrygana, the main semi-natural habitat in the region using field observation techniques, transect walks, pan traps and nest traps (Nielsen et al. 2011). In general, northern climates are less diverse. Nilsson (2003) recorded 284 species in a Swedish study (Michener 2007).

In the nine-county study area of the SHP from 2013-2014, we collected 127 species of wild bees representing 58 genera (Chapter II). There were no studies within the region to compare richness, so we referenced studies from semi-arid prairies in Oregon and Wyoming and the Northern Great Plains in South Dakota. Kimoto et al. (2012a) collected bees in 2007-2008 with blue vane traps in the Zumwalt high altitude bunchgrass

prairie in northeast Oregon. They found 94 species and 117 morphospecies of wild bees on sixteen 40 ha study plots. In another high altitude shortgrass prairie in the Laramie Basin in Wyoming, researchers collected 200 species of bees in 43 genera with nets on two sites totaling 2.6 ha (Tepedino and Stanton 1981). In the Brookings, SD, a survey of the USDA-ARS North Central Agricultural Research Laboratory research farm identified 114 pollinator species (Mogren et al. 2016). Michener (2007) stated that warm-temperate grasslands of the Southern Great Plains have a moderate fauna of wild bee populations, especially in the more arid environments with xeric vegetation. Although wild bee richness in the SHP is not comparable to the species-rich areas of the Mediterranean and Madrean, it is similar to other bunch grass and shortgrass prairies.

This is also the first study in the SHP to examine how effective CRP has been in providing habitat for pollinators. Our data show that CRP in its current form in the SHP was consistently lower in abundance, richness, and diversity of potential pollinators than cropland and native grasslands. The introduced tall grasses in the uplands disrupt native ecosystem functions (D'Antonio and Vitousek 1992, O'Connell et al. 2012), primarily by reducing playa inundation (O'Connell et al. 2012). Inadequate water runoff in playas resulted in fewer wetland flowering forbs (Chapter IV), and lack of flowering forbs in the upland seed mix reduced potential forage for pollinators. Additionally, the density of the introduced grasses may have reduced nesting opportunities for solitary bees.

The SHP has one of the highest concentrations of CRP in the country (Farm Service Agency 2017) and has potential to become valuable as pollinator habitat primarily because of the amount of land enrolled. CRP does not allow grazing except for emergency exemptions (Stubbs 2014). Future CRP plantings should be designed to

incorporate native grasses and a variety of native, nectar-rich flowers (Isaacs et al. 2009) into the landscape with the goal to enhance overall plant and insect biodiversity rather than pollination service alone (Chateil and Porcher 2015). In a landscape where most of the native shortgrass prairie is actively grazed by cattle (Smith 2003), CRP could provide pockets of minimally disturbed habitat to serve as refugia for more specialized pollinators (Basu et al. 2016).

Flower-rich filter strips around playas may provide valuable habitat for pollinators, especially in cropland. Our study demonstrated that croplands had the highest abundance, richness and diversity of potential pollinators among land uses, and the protected area around the playa was likely the reason. Conservation programs should focus on enhancing wetlands in addition to uplands (O'Connell et al. 2012). Playa conservation should include incorporating buffer strips with a native floral component. Kohler et al. (2008) determined that planting flower-rich habitats alone are not as effective for diverse pollinator communities as pre-existing natural areas. Smith and Haukos (2002) recommended that large playas with intact native shortgrass prairie watersheds should be the focus of playa conservation. Therefore, protecting and conserving high quality, minimally disturbed playas should also be a priority for pollinator conservation in this region.

Further research is needed to determine the effects of grazing on CRP flowering forb cover in the SHP. Additional studies should be longer than two years and include years in more temperate climate conditions to determine how pollinators respond to land use outside of drought years.

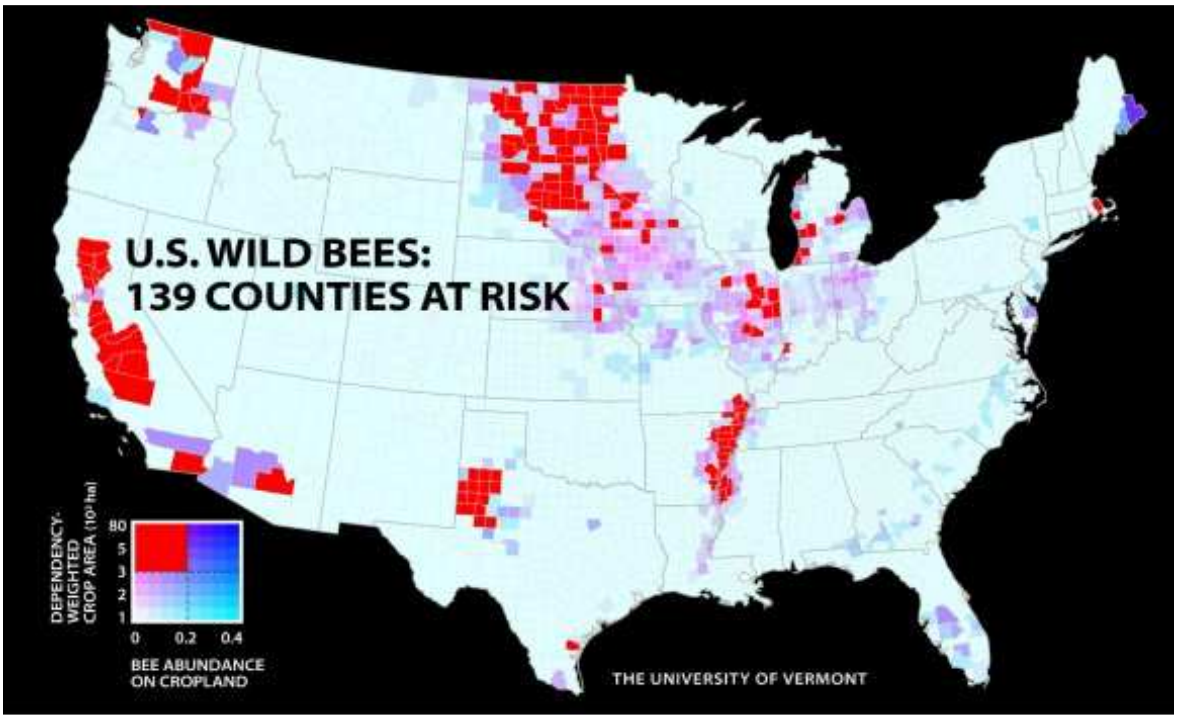



Figure III.1. Koh et al. (2016) determined that 139 counties are at risk for a shortage of pollination service from wild bees due to declining bee populations and increasing demand for crop pollination. The counties highlighted in red are at greatest risk.

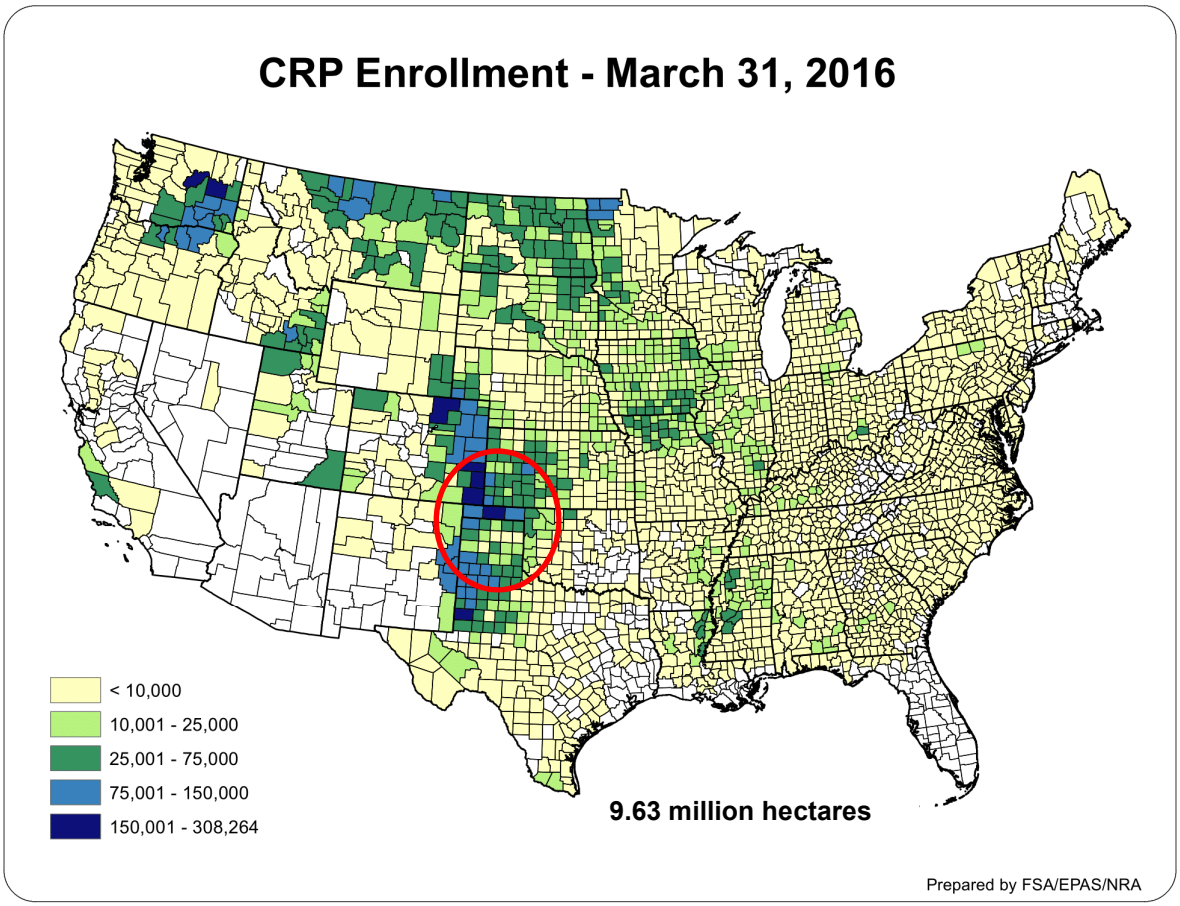



Figure III.2. Conservation Reserve Program enrollment by county in 2016 (Farm Service Agency 2017).

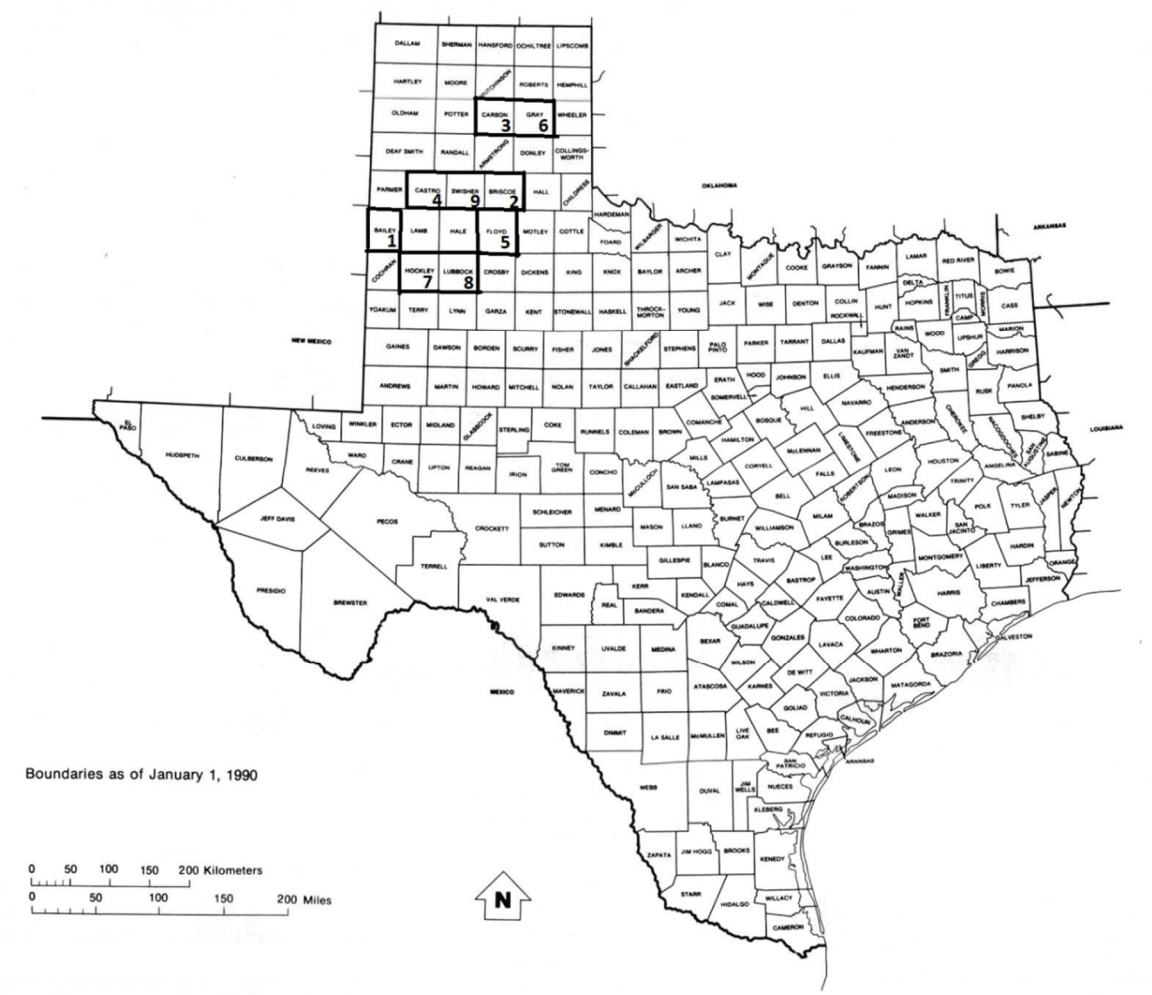



Figure III.3. Texas High Plains counties included in 2013 and 2014 pollinator study. 1. Bailey 2. Briscoe 3. Carson 4. Castro 5. Floyd 6. Gray 7. Hockley 8. Lubbock 9. Swisher. Map courtesy of the University of Texas Libraries, The University of Texas at Austin.

Figure III.4. Example of sampling site for 2013-2014 study in Texas High Plains. There was a playa and its catchment for each land use in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties. There were three sets of parallel transects in the playa and three sets in the uplands for a total of 27 sampling sites. Data from the playas and uplands were pooled separately into two sampling units.

Table III.1. Dates of sampling periods when pollinators were collected by blue vane traps and sweep netting during 2013 and 2014 in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains. Each county was sampled once during the sampling period. Data were pooled by year for each sampling period in the analyses.

| **Sampling Period** | **2013** | **2014** |
|---|---|---|
| 1 | March 31 – April 14 | March 30 – April 12 |
| 2 | April 14 – April 27 | April 13 – April 26 |
| 3 | April 28 – May 11 | April 27 – May 10 |
| 4 | May 12 – May 25 | May 11 – May 24 |
| 5 | May 26 – June 8 | May 25 – June 7 |
| 6 | June 9 – June 22 | June 8 – June 21 |
| 7 | June 23 – July 6 | June 22 – July 5 |
| 8 | July 7 – July 20 | July 6 – July 19 |
| 9 | July 21 – August 3 | July 20 – August 2 |
| 10 | August 4 – August 17 | August 3 – August 16 |
| 11 | August 18 – August 31 | August 17 – August 30 |
| 12 | September 1 – September 14 | August 31 – September 13 |
| 13 | September 15 – September 28 | September 14 – September 27 |

Table III.2. ANCOVA on effects of sampling period, land use and land type on pollinator abundance from specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table III.1.

| **Index** | **F-Value, df** | **p-value** |
|---|---|---|
| ***Abundance*** | | |
| *Total* | | |
| Sampling period | F (12,1244) = 7.94 | <0.000 |
| Land Use | F (2,1244) = 9.54 | <0.000 |
| Land Type | F (1,1244) = 3.18 | 0.075 |
| Sampling period x Land Use | F (24,1244) = 4.08 | <0.000 |
| Sampling period x Land Type | F (12,1244) = 1.14 | 0.322 |
| Land Use x Land Type | F (2,1244) = 1.34 | 0.263 |
| Sampling period x Land Use x Land Type | F (24,1244) = 0.47 | 0.986 |
| Hours traps in field | F (1,1244) = 30.17 | <0.000 |
| *Hymenoptera* | | |
| Sampling period | F (12,1244) = 6.79 | <0.000 |
| Land Use | F (2,1244) = 7.88 | <0.000 |
| Land Type | F (1,1244) = 10.35 | 0.001 |
| Sampling period x Land Use | F (24,1244) = 2.97 | <0.000 |
| Sampling period x Land Type | F (12,1244) = 0.47 | 0.935 |
| Land Use x Land Type | F (2,1244) = 1.56 | 0.210 |
| Sampling period x Land Use x Land Type | F (24,1244) = 0.38 | 0.997 |
| Hours traps in field | F (1,1244) = 14.84 | <0.000 |
| *Diptera* | | |
| Sampling period | F (12,1244) = 7.09 | <0.000 |
| Land Use | F (2,1244) = 13.31 | <0.000 |
| Land Type | F (1,1244) = 1.21 | 0.272 |
| Sampling period x Land Use | F (24,1244) = 1.13 | 0.297 |
| Sampling period x Land Type | F (12,1244) = 0.26 | 0.994 |
| Land Use x Land Type | F (2,1244) = 1.40 | 0.248 |
| Sampling period x Land Use x Land Type | F (24,1244) = 0.42 | 0.994 |
| Hours traps in field | F (1,1244) = 3.42 | 0.065 |
| *Coleoptera* | | |
| Sampling period | F (12,1244) = 13.28 | <0.000 |
| Land Use | F (2,1244) = 3.37 | 0.035 |
| Land Type | F (1,1244) = 1.37 | 0.243 |
| Sampling period x Land Use | F (24,1244) = 3.89 | <0.000 |
| Sampling period x Land Type | F (12,1244) = 1.99 | 0.022 |
| Land Use x Land Type | F (2,1244) = 0.70 | 0.496 |
| Sampling period x Land Use x Land Type | F (24,1244) = 0.57 | 0.953 |
| Hours traps in field | F (1,1244) = 22.01 | <0.000 |
| *Lepidoptera* | | |
| Sampling period | F (12,1244) = 21.77 | <0.000 |
| Land Use | F (2,1244) = 12.99 | <0.000 |
| Land Type | F (1,1244) = 0.01 | 0.913 |
| Sampling period x Land Use | F (24,1244) = 4.46 | <0.000 |

Table III.2 Continued

| | | |
|---|---|---|
| Sampling period x Land Type | F (12,1244) = 0.47 | 0.934 |
| Land Use x Land Type | F (2,1244) = 0.63 | 0.534 |
| Sampling period x Land Use x Land Type | F (24,1244) = 0.40 | 0.996 |
| Hours traps in field | F (1,1244) = 0.12 | 0.729 |

Table III.3. ANCOVA on effects of sampling period, land use and land type effects on pollinator species richness from specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are in Table III.1.

| Index | Source | F-Value, df | p-value |
|---|---|---|---|
| ***Species Richness*** | | | |
| | *Total* | | |
| | Sampling period | F (12,1244) = 12.79 | <0.000 |
| | Land Use | F (2,1244) = 12.61 | <0.000 |
| | Land Type | F (1,1244) = 19.09 | <0.000 |
| | Sampling period x Land Use | F (24,1244) = 1.00 | 0.424 |
| | Sampling period x Land Type | F (12,1244) = 0.56 | 0.907 |
| | Land Use x Land Type | F (2,1244) = 2.30 | 0.111 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.24 | 1.000 |
| | Hours traps in field | F (1,1244) = 25.05 | <0.000 |
| | *Hymenoptera* | | |
| | Sampling period | F (12,1244) = 10.19 | <0.000 |
| | Land Use | F (2,1244) = 10.34 | <0.000 |
| | Land Type | F (1,1244) = 23.08 | <0.000 |
| | Sampling period x Land Use | F (24,1244) = 0.89 | 0.580 |
| | Sampling period x Land Type | F (12,1244) = 0.57 | 0.904 |
| | Land Use x Land Type | F (2,1244) = 1.48 | 0.244 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.19 | 1.000 |
| | Hours traps in field | F (1,1244) = 29.47 | <0.000 |
| | *Diptera* | | |
| | Sampling period | F (12,1244) = 13.34 | <0.000 |
| | Land Use | F (2,1244) = 11.86 | <0.000 |
| | Land Type | F (1,1244) = 1.32 | 0.258 |
| | Sampling period x Land Use | F (24,1244) = 1.24 | 0.192 |
| | Sampling period x Land Type | F (12,1244) = 0.29 | 0.991 |
| | Land Use x Land Type | F (2,1244) = 2.34 | 0.100 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.62 | 0.921 |
| | Hours traps in field | F (1,1244) = 29.47 | <0.000 |
| | *Coleoptera* | | |
| | Sampling period | F (12,1244) = 25.84 | <0.000 |
| | Land Use | F (2,1244) = 9.24 | <0.000 |
| | Land Type | F (1,1244) = 7.88 | 0.006 |
| | Sampling period x Land Use | F (24,1244) = 2.19 | 0.001 |
| | Sampling period x Land Type | F (12,1244) = 1.22 | 0.282 |
| | Land Use x Land Type | F (2,1244) = 0.27 | 0.795 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.73 | 0.839 |
| | Hours traps in field | F (1,1244) = 5.87 | 0.016 |
| | *Lepidoptera* | | |
| | Sampling period | F (12,1244) = 19.14 | <0.000 |
| | Land Use | F (2,1244) = 4.09 | 0.018 |
| | Land Type | F (1,1244) = 2.28 | 0.136 |
| | Sampling period x Land Use | F (24,1244) = 1.24 | 0.198 |

Table III.3 Continued

| | | |
|---|---|---|
| Sampling period x Land Type | F (12,1244) = 0.29 | 0.991 |
| Land Use x Land Type | F (2,1244) = 2.21 | 0.113 |
| Sampling period x Land Use x Land Type | F (24,1244) = 1.18 | 0.243 |
| Hours traps in field | F (1,1244) = 0.02 | 0.894 |

Table III.4. ANCOVA results for effects of sampling period, land use and land type on pollinator Shannon-Wiener diversity from specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table III.1.

| Index | Source | F-Value, df | p-value |
|---|---|---|---|
| ***Shannon-Weiner Diversity Index*** | | | |
| | *Total* | | |
| | Sampling period | F (12,1244) = 8.12 | <0.000 |
| | Land Use | F (2,1244) = 9.72 | <0.000 |
| | Land Type | F (1,1244) = 16.49 | <0.000 |
| | Sampling period x Land Use | F (24,1244) = 1.31 | 0.147 |
| | Sampling period x Land Type | F (12,1244) = 1.06 | 0.395 |
| | Land Use x Land Type | F (2,1244) = 0.77 | 0.462 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.38 | 0.997 |
| | Hours traps in field | F (1,1244) = 10.59 | 0.001 |
| | *Hymenoptera* | | |
| | Sampling period | F (12,1244) = 9.70 | <0.000 |
| | Land Use | F (2,1244) = 5.83 | 0.003 |
| | Land Type | F (1,1244) = 25.25 | <0.000 |
| | Sampling period x Land Use | F (24,1244) = 0.90 | 0.605 |
| | Sampling period x Land Type | F (12,1244) = 1.06 | 0.391 |
| | Land Use x Land Type | F (2,1244) = 0.90 | 0.407 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.33 | 0.999 |
| | Hours traps in field | F (1,1244) = 25.13 | <0.000 |
| | *Diptera* | | |
| | Sampling period | F (12,1244) = 10.54 | <0.000 |
| | Land Use | F (2,1244) = 5.04 | 0.007 |
| | Land Type | F (1,1244) = 0.70 | 0.404 |
| | Sampling period x Land Use | F (24,1244) = 0.93 | 0.558 |
| | Sampling period x Land Type | F (12,1244) = 0.68 | 0.775 |
| | Land Use x Land Type | F (2,1244) = 2.38 | 0.093 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.61 | 0.928 |
| | Hours traps in field | F (1,1244) = 8.86 | 0.003 |
| | *Coleoptera* | | |
| | Sampling period | F (12,1244) = 17.99 | <0.000 |
| | Land Use | F (2,1244) = 10.11 | <0.000 |
| | Land Type | F (1,1244) = 3.59 | 0.058 |
| | Sampling period x Land Use | F (24,1244) = 1.43 | 0.083 |
| | Sampling period x Land Type | F (12,1244) = 1.89 | 0.032 |
| | Land Use x Land Type | F (2,1244) = 0.20 | 0.819 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 0.58 | 0.948 |
| | Hours traps in field | F (1,1244) = 1.27 | 0.261 |
| | *Lepidoptera* | | |
| | Sampling period | F (12,1244) = 11.51 | <0.000 |
| | Land Use | F (2,1244) = 0.83 | 0.438 |
| | Land Type | F (1,1244) = 0.45 | 0.500 |
| | Sampling period x Land Use | F (24,1244) = 1.44 | 0.076 |

Table III.4 Continued

| | | |
|---|---|---|
| Sampling period x Land Type | F (12,1244) = 0.62 | 0.827 |
| Land Use x Land Type | F (2,1244) = 1.25 | 0.286 |
| Sampling period x Land Use x Land Type | F (24,1244) = 1.74 | 0.015 |
| Hours traps in field | F (1,1244) = 0.02 | 0.884 |

Table III.5. ANOVA results for effects of sampling period, land use and land type on pollinator abundance from specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table III.1.

| Index | Source | F-Value, df | p-value |
|---|---|---|---|
| ***Abundance*** | | | |
| | *Total* | | |
| | Sampling period | F (12,1149) = 11.75 | <0.000 |
| | Land Use | F (2,1149) = 6.93 | 0.001 |
| | Land Type | F (1,1149) = 1.05 | 0.307 |
| | Sampling period x Land Use | F (24,1149) = 2.26 | <0.000 |
| | Sampling period x Land Type | F (12,1149) = 2.02 | 0.020 |
| | Land Use x Land Type | F (2,1149) = 0.68 | 0.508 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 0.61 | 0.931 |
| | *Hymenoptera* | | |
| | Sampling period | F (12,1149) = 4.08 | <0.000 |
| | Land Use | F (2,1149) = 4.04 | 0.018 |
| | Land Type | F (1,1149) = 5.96 | 0.015 |
| | Sampling period x Land Use | F (24,1149) = 0.95 | 0.534 |
| | Sampling period x Land Type | F (12,1149) = 2.65 | 0.002 |
| | Land Use x Land Type | F (2,1149) = 1.68 | 0.187 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 1.11 | 0.321 |
| | *Diptera* | | |
| | Sampling period | F (12,1153) = 2.76 | 0.001 |
| | Land Use | F (2,1153) = 0.08 | 0.925 |
| | Land Type | F (1,1153) = 0.60 | 0.437 |
| | Sampling period x Land Use | F (24,1153) = 2.15 | 0.001 |
| | Sampling period x Land Type | F (12,1153) = 1.88 | 0.033 |
| | Land Use x Land Type | F (2,1153) = 2.23 | 0.108 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 0.82 | 0.720 |
| | *Coleoptera* | | |
| | Sampling period | F (12,1153) = 10.71 | <0.000 |
| | Land Use | F (2,1153) = 7.11 | 0.001 |
| | Land Type | F (1,1153) = 0.04 | 0.846 |
| | Sampling period x Land Use | F (24,1153) = 1.92 | 0.005 |
| | Sampling period x Land Type | F (12,1153) = 0.95 | 0.494 |
| | Land Use x Land Type | F (2,1153) = 1.69 | 0.186 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 0.51 | 0.978 |
| | *Lepidoptera* | | |
| | Sampling period | F (12,1153) = 4.11 | <0.000 |
| | Land Use | F (2,1153) = 0.73 | 0.483 |
| | Land Type | F (1,1153) = 1.19 | 0.276 |
| | Sampling period x Land Use | F (24,1153) = 1.08 | 0.357 |
| | Sampling period x Land Type | F (12,1153) = 1.04 | 0.406 |
| | Land Use x Land Type | F (2,1153) = 0.35 | 0.707 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 1.11 | 0.330 |

Table III.6. ANOVA results for effects of sampling period, land use and land type on pollinator species richness from specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table III.1.

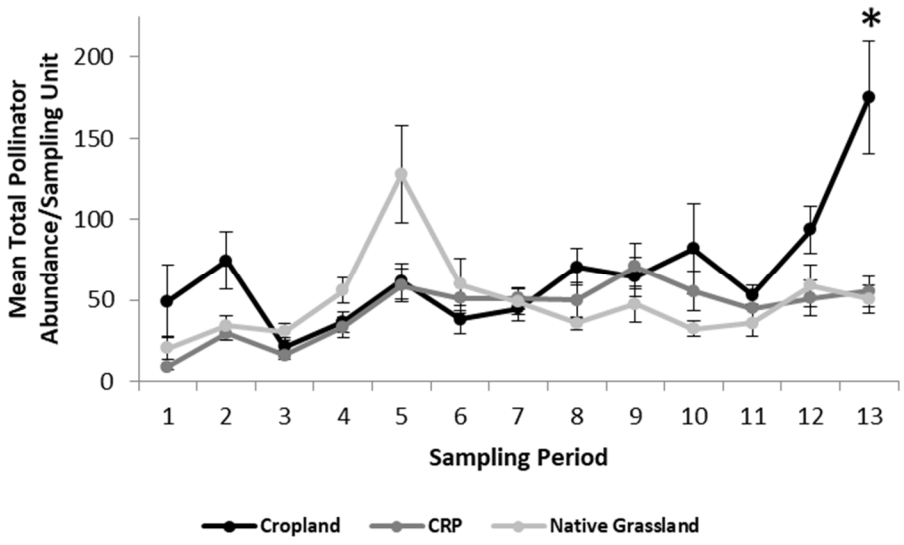
| Index | Source | F-Value, df | p-value |
|---|---|---|---|
| ***Species Richness*** | | | |
| | *Total* | | |
| | Sampling period | F (12,1149) = 14.16 | <0.000 |
| | Land Use | F (2,1149) = 7.69 | <0.000 |
| | Land Type | F (1,1149) = 0.80 | 0.370 |
| | Sampling period x Land Use | F (24,1149) = 2.44 | <0.000 |
| | Sampling period x Land Type | F (12,1149) = 1.89 | 0.032 |
| | Land Use x Land Type | F (2,1149) = 0.20 | 0.817 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 0.94 | 0.543 |
| | *Hymenoptera* | | |
| | Sampling period | F (12,1149) = 5.82 | <0.000 |
| | Land Use | F (2,1149) = 3.72 | 0.025 |
| | Land Type | F (1,1149) = 1.70 | 0.192 |
| | Sampling period x Land Use | F (24,1149) = 1.17 | 0.263 |
| | Sampling period x Land Type | F (12,1149) = 2.19 | 0.010 |
| | Land Use x Land Type | F (2,1149) = 1.65 | 0.192 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 1.33 | 0.133 |
| | *Diptera* | | |
| | Sampling period | F (12,1153) = 4.45 | <0.000 |
| | Land Use | F (2,1153) = 1.16 | 0.315 |
| | Land Type | F (1,1153) = 3.15 | 0.076 |
| | Sampling period x Land Use | F (24,1153) = 2.56 | <0.000 |
| | Sampling period x Land Type | F (12,1153) = 1.78 | 0.047 |
| | Land Use x Land Type | F (2,1153) = 1.08 | 0.339 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 1.39 | 0.102 |
| | *Coleoptera* | | |
| | Sampling period | F (12,1153) = 13.36 | <0.000 |
| | Land Use | F (2,1153) = 9.22 | <0.000 |
| | Land Type | F (1,1153) = 3.21 | 0.073 |
| | Sampling period x Land Use | F (24,1153) = 2.01 | 0.003 |
| | Sampling period x Land Type | F (12,1153) = 1.11 | 0.348 |
| | Land Use x Land Type | F (2,1153) = 0.97 | 0.379 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 1.04 | 0.410 |
| | *Lepidoptera* | | |
| | Sampling period | F (12,1153) = 4.33 | <0.000 |
| | Land Use | F (2,1153) = 2.01 | 0.134 |
| | Land Type | F (1,1153) = 0.43 | 0.511 |
| | Sampling period x Land Use | F (24,1153) = 1.15 | 0.283 |
| | Sampling period x Land Type | F (12,1153) = 1.34 | 0.190 |
| | Land Use x Land Type | F (2,1153) = 0.27 | 0.761 |
| | Sampling period x Land Use x Land Type | F (24,1244) = 1.18 | 0.243 |

Table III.7. ANOVA results for effects of sampling period, land use and land type on pollinator Shannon-Wiener diversity from specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table III.1.

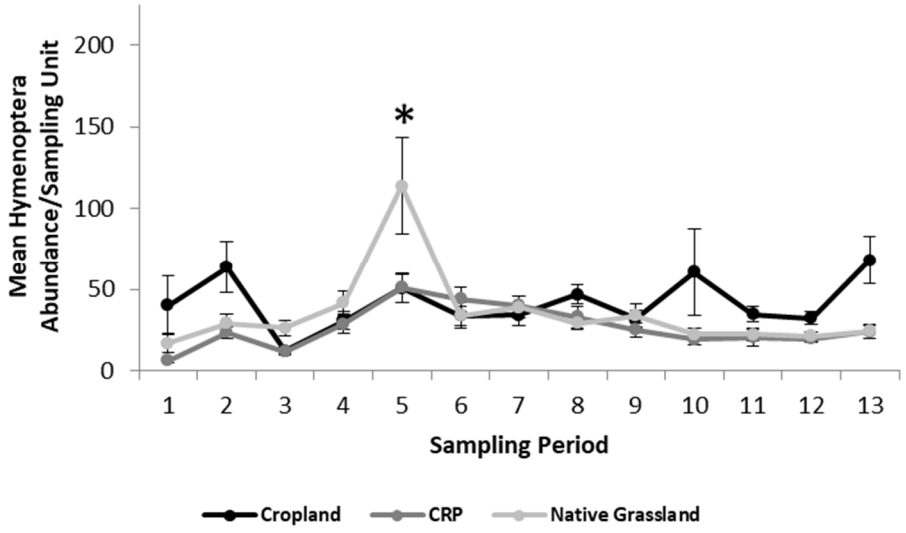
| Index | Source | F-Value, df | p-value |
|---|---|---|---|
| ***Shannon-Wiener Diversity*** | | | |
| | *Total* | | |
| | Sampling period | F (12,1149) = 10.54 | <0.000 |
| | Land Use | F (2,1149) = 5.46 | 0.004 |
| | Land Type | F (1,1149) = 1.02 | 0.313 |
| | Sampling period x Land Use | F (24,1149) = 1.68 | 0.021 |
| | Sampling period x Land Type | F (12,1149) = 1.72 | 0.058 |
| | Land Use x Land Type | F (2,1149) = 0.56 | 0.569 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 0.98 | 0.495 |
| | *Hymenoptera* | | |
| | Sampling period | F (12,1149) = 3.02 | <0.000 |
| | Land Use | F (2,1149) = 2.64 | 0.072 |
| | Land Type | F (1,1149) = 1.29 | 0.256 |
| | Sampling period x Land Use | F (24,1149) = 0.95 | 0.537 |
| | Sampling period x Land Type | F (12,1149) = 1.75 | 0.052 |
| | Land Use x Land Type | F (2,1149) = 0.55 | 0.575 |
| | Sampling period x Land Use x Land Type | F (24,1149) = 1.25 | 0.186 |
| | *Diptera* | | |
| | Sampling period | F (12,1153) = 2.01 | 0.021 |
| | Land Use | F (2,1153) = 1.32 | 0.267 |
| | Land Type | F (1,1153) = 3.09 | 0.079 |
| | Sampling period x Land Use | F (24,1153) = 2.00 | 0.003 |
| | Sampling period x Land Type | F (12,1153) = 2.17 | 0.011 |
| | Land Use x Land Type | F (2,1153) = 1.05 | 0.350 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 1.97 | 0.004 |
| | *Coleoptera* | | |
| | Sampling period | F (12,1153) = 6.24 | <0.000 |
| | Land Use | F (2,1153) = 6.55 | 0.001 |
| | Land Type | F (1,1153) = 4.22 | 0.040 |
| | Sampling period x Land Use | F (24,1153) = 1.38 | 0.102 |
| | Sampling period x Land Type | F (12,1153) = 0.63 | 0.816 |
| | Land Use x Land Type | F (2,1153) = 2.35 | 0.096 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 1.08 | 0.357 |
| | *Lepidoptera* | | |
| | Sampling period | F (12,1153) = 1.64 | 0.076 |
| | Land Use | F (2,1153) = 1.92 | 0.147 |
| | Land Type | F (1,1153) = 0.00 | 0.957 |
| | Sampling period x Land Use | F (24,1153) = 0.72 | 0.837 |
| | Sampling period x Land Type | F (12,1153) = 0.66 | 0.789 |
| | Land Use x Land Type | F (2,1153) = 0.15 | 0.862 |
| | Sampling period x Land Use x Land Type | F (24,1153) = 0.87 | 0.646 |

Figure III.5. Effects of sampling period, land use, and land type on pollinator abundance for specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between a land use and sampling period interaction or land type and sampling period interaction during a particular sampling period, it is designated with an asterisk (*). Total season land uses and sampling periods with the same letter are not statistically different. a.) Total abundance – sampling period x land use, b.) Hymenoptera abundance – sampling period x land use, c.) Diptera abundance – sampling period, d.) Diptera abundance – land use, e.) Coleoptera abundance – sampling period x land use, f.) Coleoptera abundance – sampling period x land type, g.) Lepidoptera abundance – sampling period x land use.

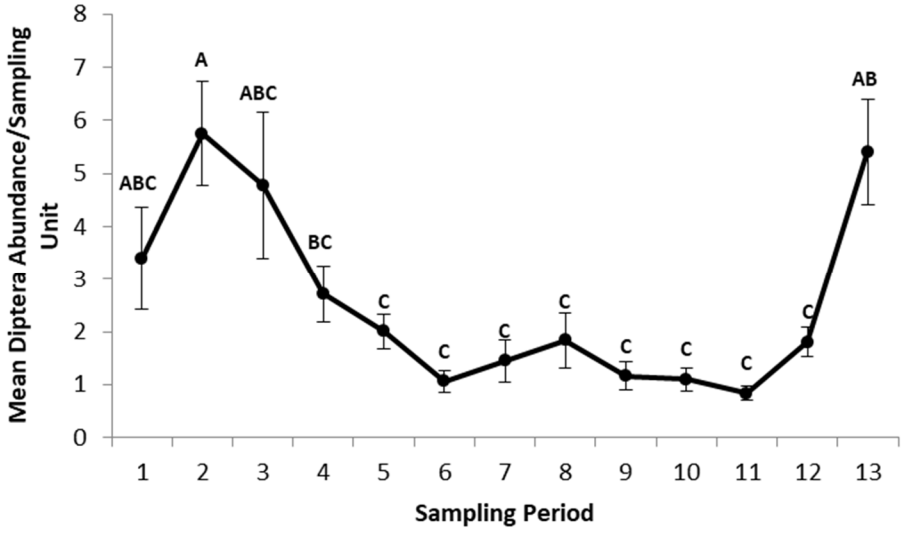
a.



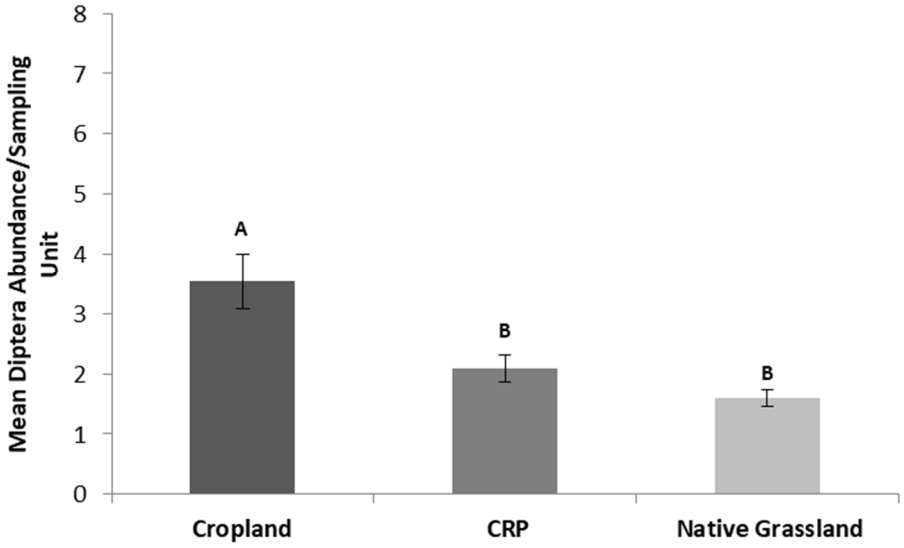
b.


Mean Hymenoptera Abundance/Sampling Unit
200
150
100
50
0
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Cropland
CRP
Native Grassland

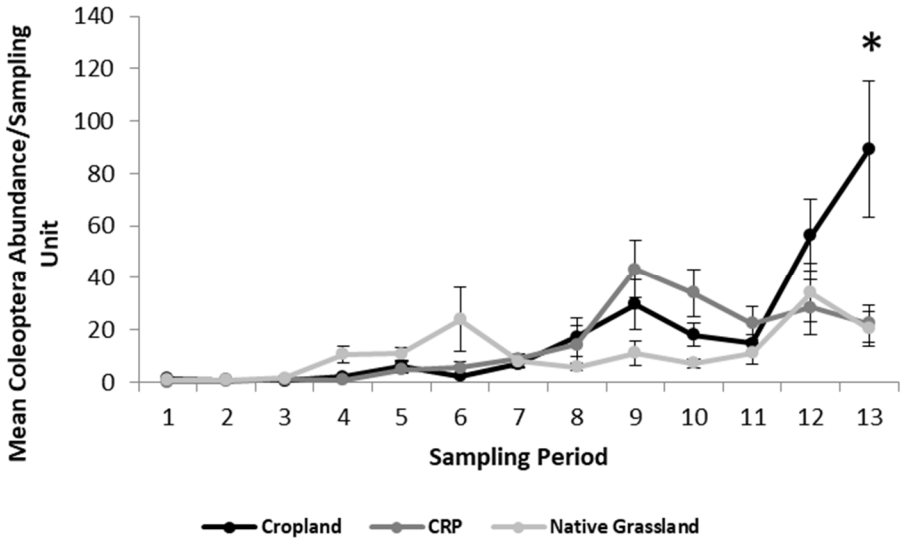
c.


Mean Diptera Abundance/Sampling Unit
8
7
6
5
4
3
2
1
0
ABC
A
ABC
BC
C
C
C
C
C
C
C
AB
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period

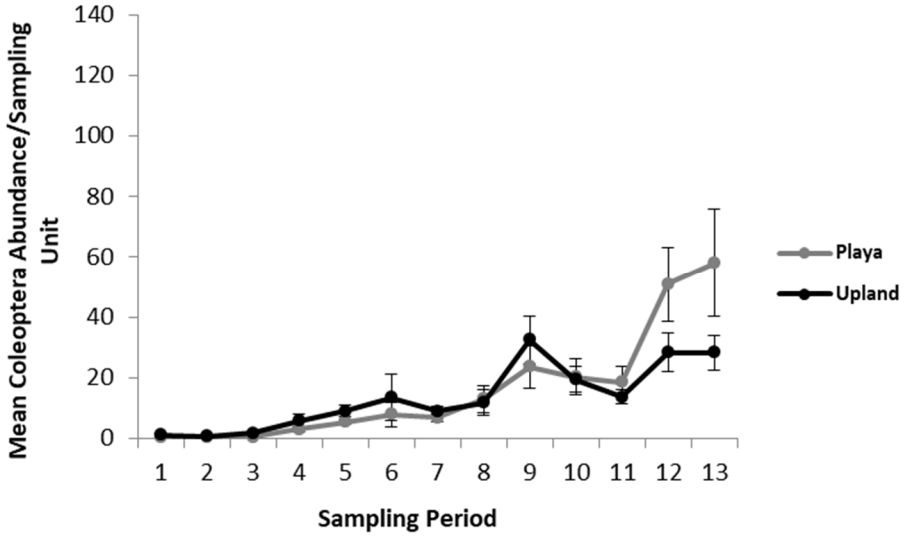
d.


Mean Diptera Abundance/Sampling Unit
8
7
6
5
4
3
2
1
0
A
B
B
Cropland
CRP
Native Grassland

e.


Mean Coleoptera Abundance/Sampling Unit
140
120
100
80
60
40
20
0
*
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Cropland
CRP
Native Grassland

f.


Mean Coleoptera Abundance/Sampling Unit
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

g.

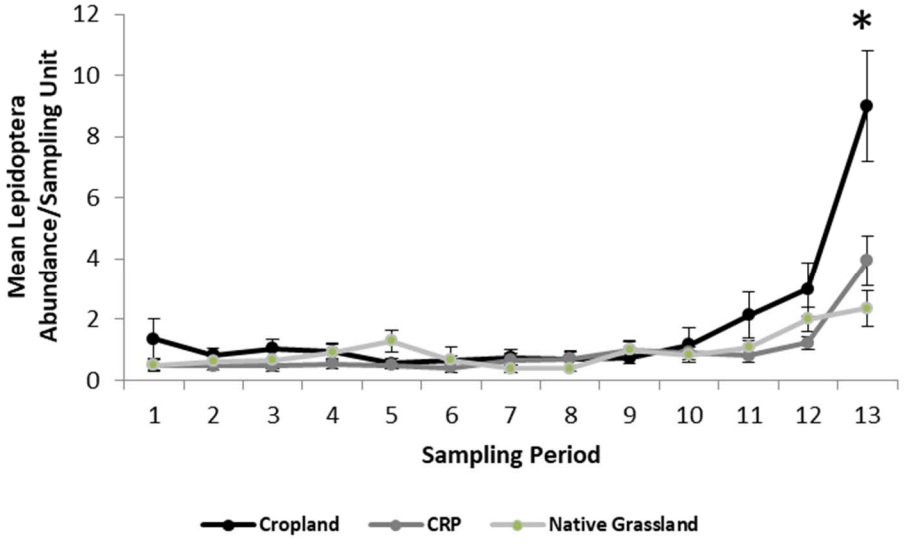
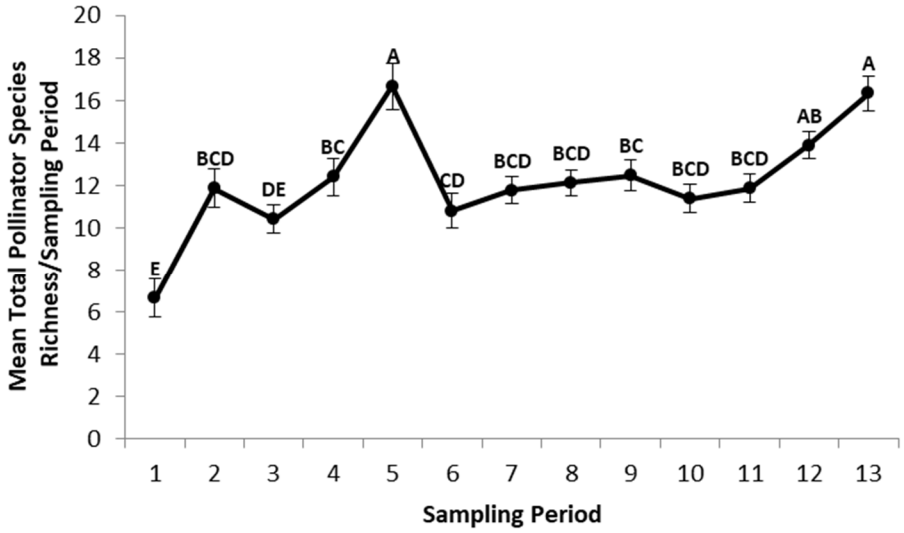
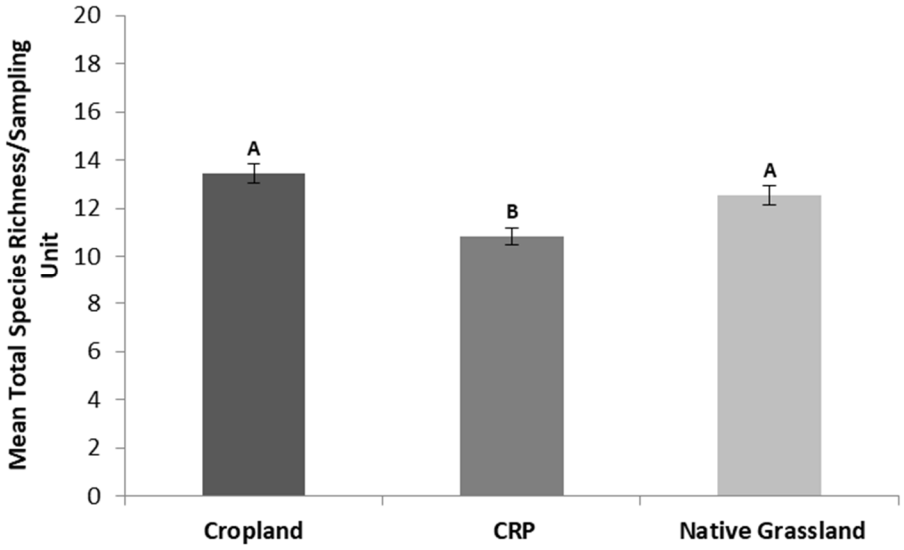

Mean Lepidoptera Abundance/Sampling Unit
12
10
8
6
4
2
0
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Cropland
CRP
Native Grassland

Figure III.6. Effects of sampling period, land use, and land type on pollinator species richness for specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between land use or land type within a sampling period interaction, it is designated with an asterisk (*). Total season land uses and periods with the same letter are not statistically different. a.) Total species richness – sampling period, b.) Total species richness – land use, c.) Hymenoptera species richness – sampling period, d.) Hymenoptera species richness – land use, e.) Diptera species richness – sampling period, f.) Diptera species richness – land use, g.) Coleoptera species richness – sampling period x land use, h.) Lepidoptera species richness – sampling period, i.) Lepidoptera species richness – land use.

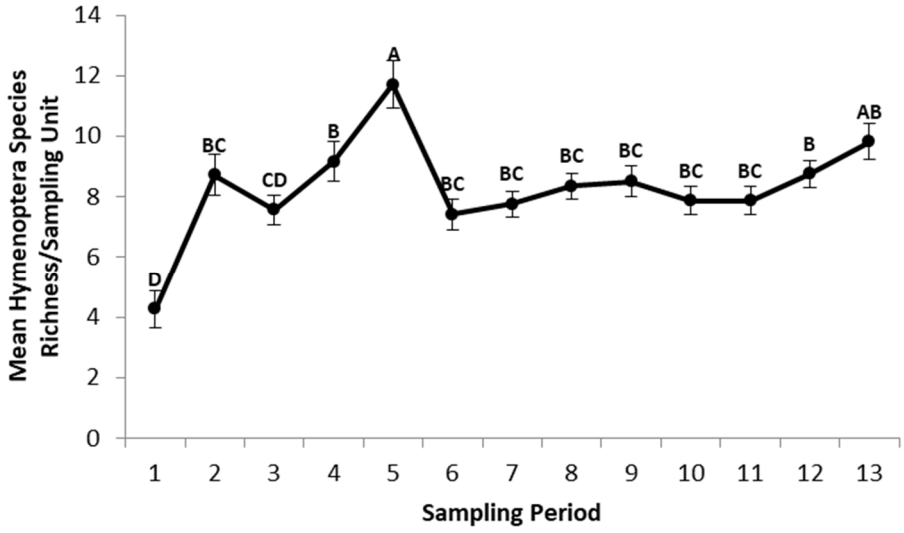
a.



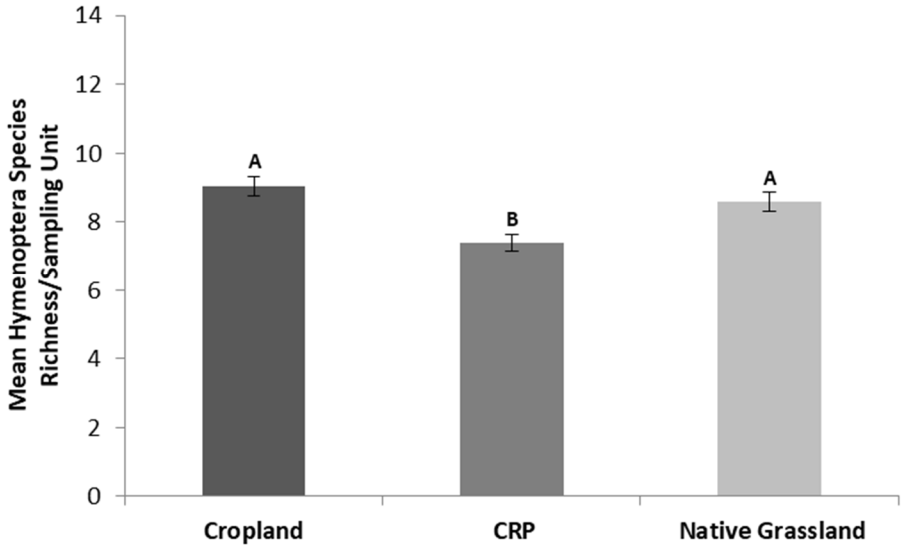
b.


Mean Total Species Richness/Sampling Unit
20
18
16
14
12
10
8
6
4
2
0
A
B
A
Cropland
CRP
Native Grassland

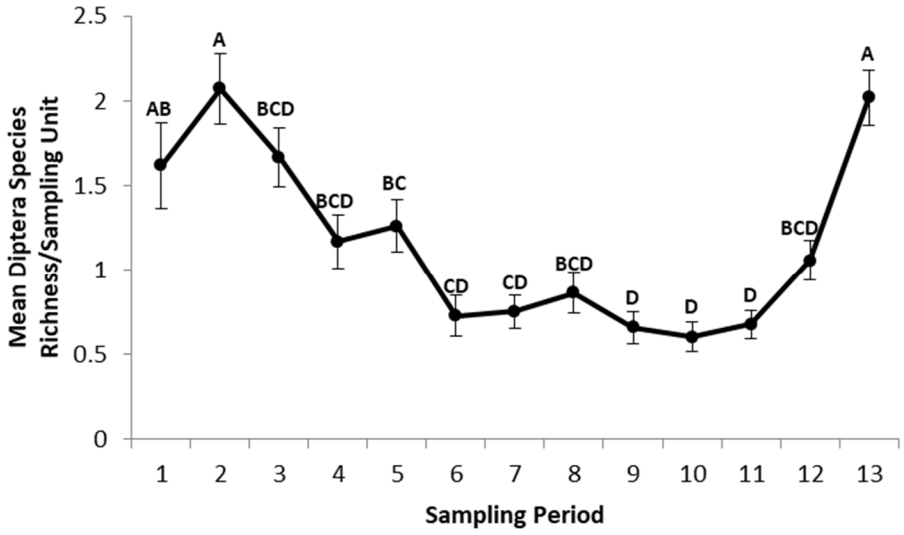
c.


Mean Hymenoptera Species Richness/Sampling Unit
14
12
10
8
6
4
2
0
D
BC
CD
B
A
BC
BC
BC
BC
BC
BC
B
AB
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

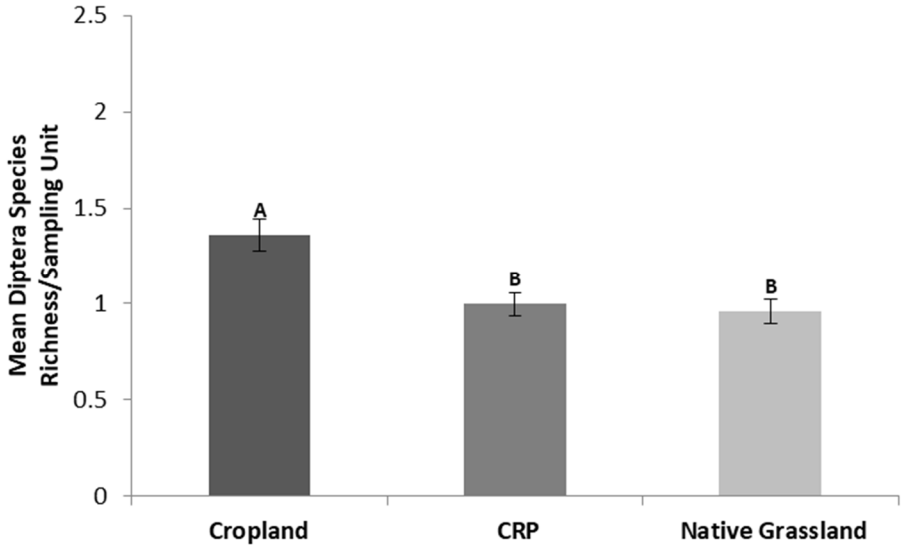
d.


Mean Hymenoptera Species Richness/Sampling Unit
14
12
10
8
6
4
2
0
A
B
A
Cropland
CRP
Native Grassland

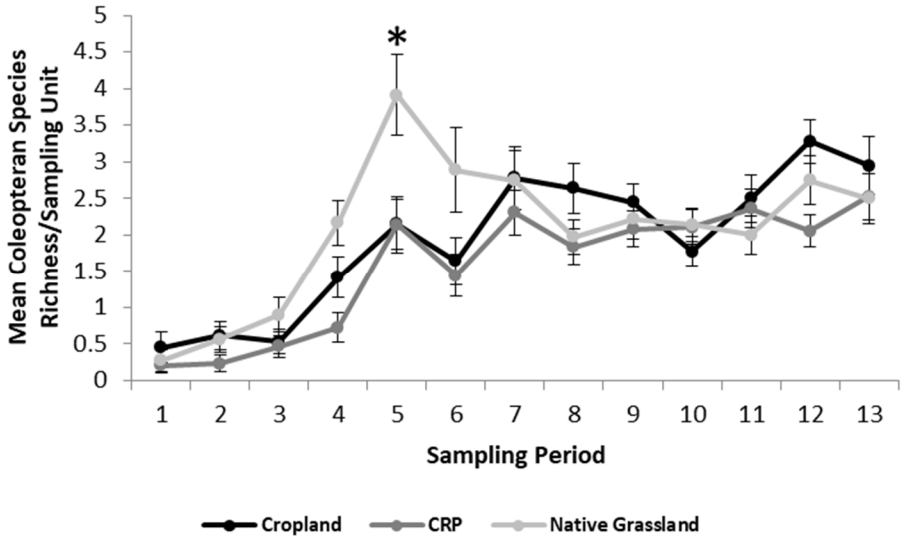
e.


Mean Diptera Species Richness/Sampling Unit
2.5
2
1.5
1
0.5
0
AB
A
BCD
BCD
BC
CD
CD
BCD
D
D
D
BCD
A
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

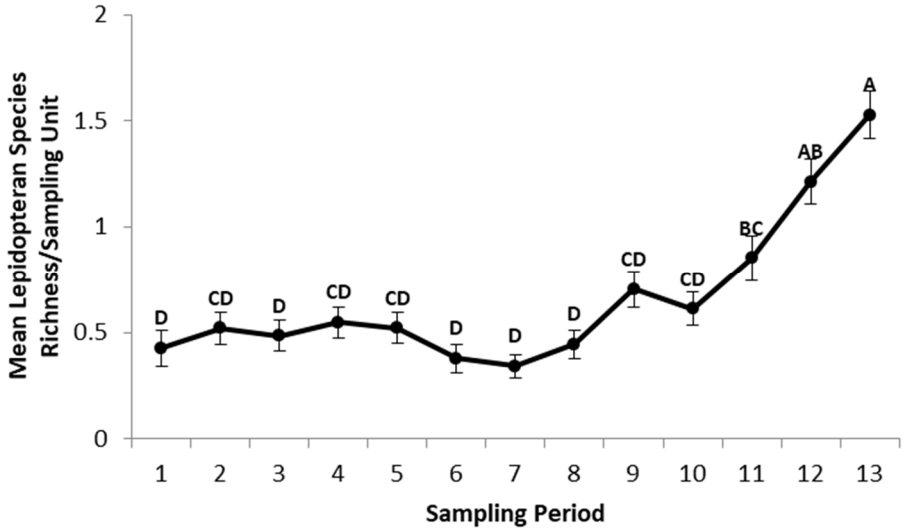
f.


Mean Diptera Species Richness/Sampling Unit
2.5
2
1.5
1
0.5
0
A
B
B
Cropland
CRP
Native Grassland

g.


Mean Coleopteran Species Richness/Sampling Unit
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
*
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Cropland
CRP
Native Grassland

h.


Mean Lepidopteran Species Richness/Sampling Unit
2
1.5
1
0.5
0
D
CD
D
CD
CD
D
D
D
CD
CD
BC
AB
A
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period

i.

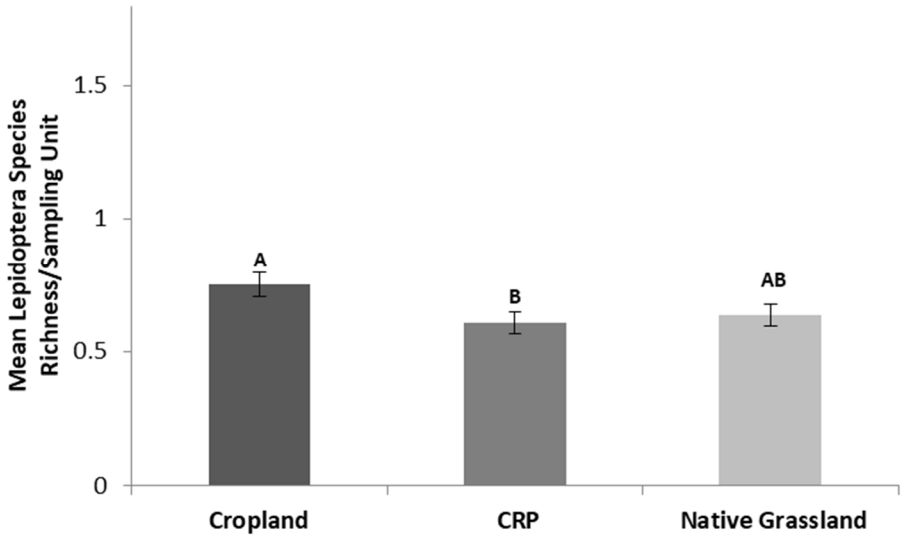
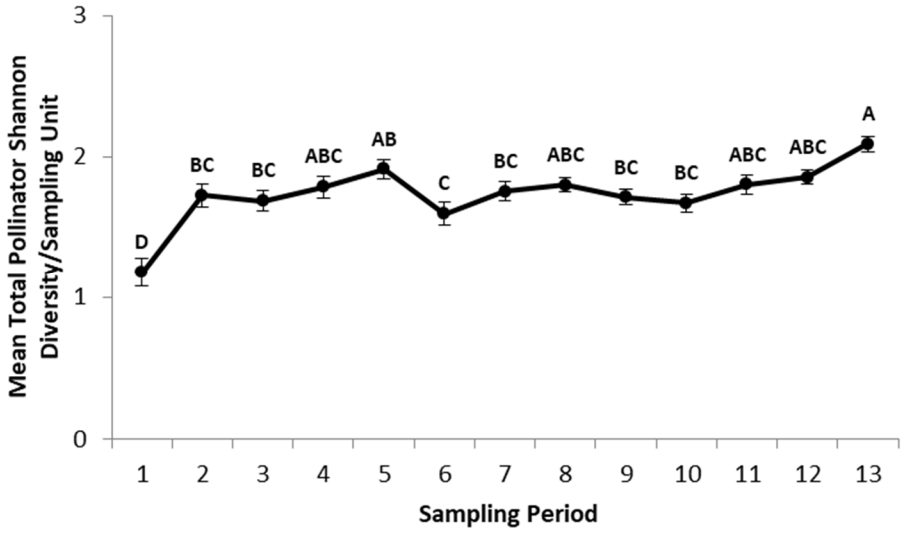
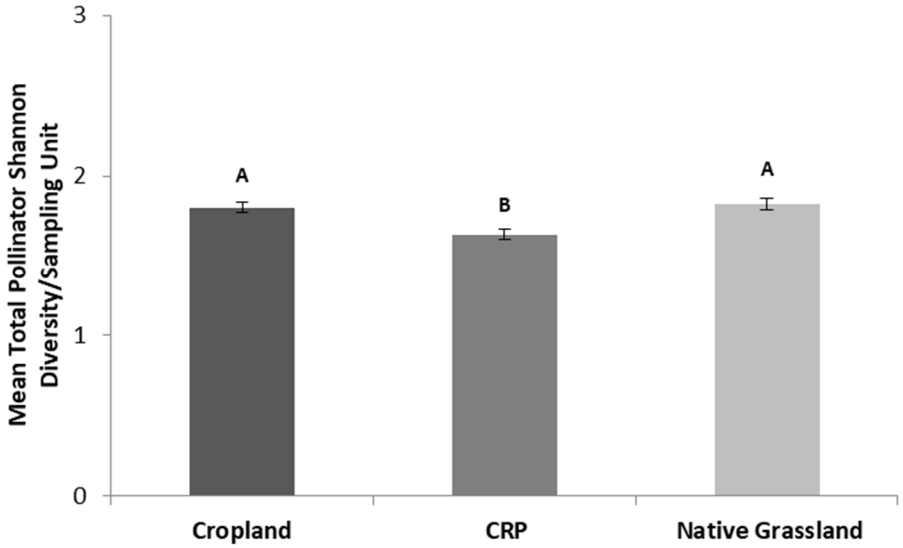

Mean Lepidoptera Species Richness/Sampling Unit
1.5
1
0.5
0
A
B
AB
Cropland
CRP
Native Grassland

Figure III.7. Effects of sampling period, land use, and land type on pollinator Shannon-Wiener diversity for specimens collected with blue vane traps in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between land use or land type within a sampling period interaction, it is designated with an asterisk (*). Total season land uses and sampling periods with the same letter are not statistically different. a.) Total diversity – sampling period, b.) Total diversity – land use, c.) Hymenoptera diversity – sampling period, d.) Hymenoptera diversity – land use, e.) Diptera diversity – sampling period, f.) Diptera diversity – land use, g.) Coleoptera diversity – land use, h.) Coleoptera diversity – sampling period x land type, i.) Lepidoptera diversity – sampling period x land use x land type.

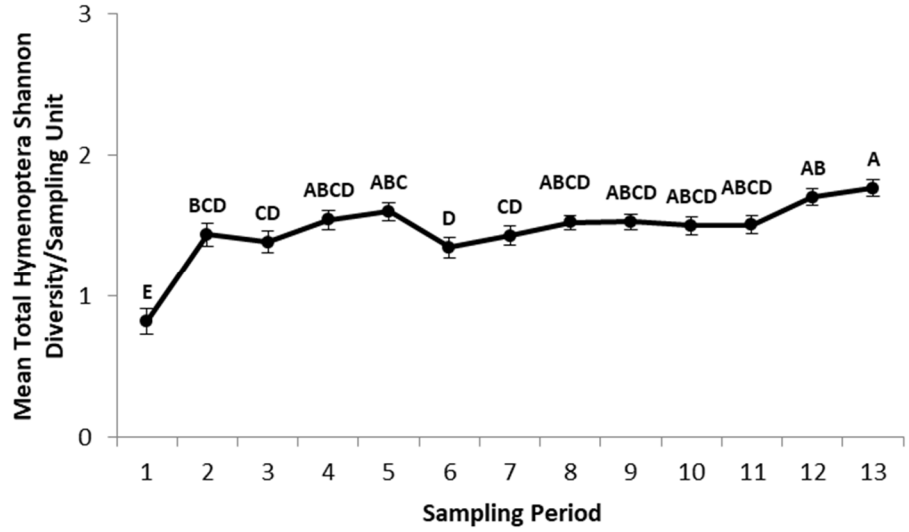
a.



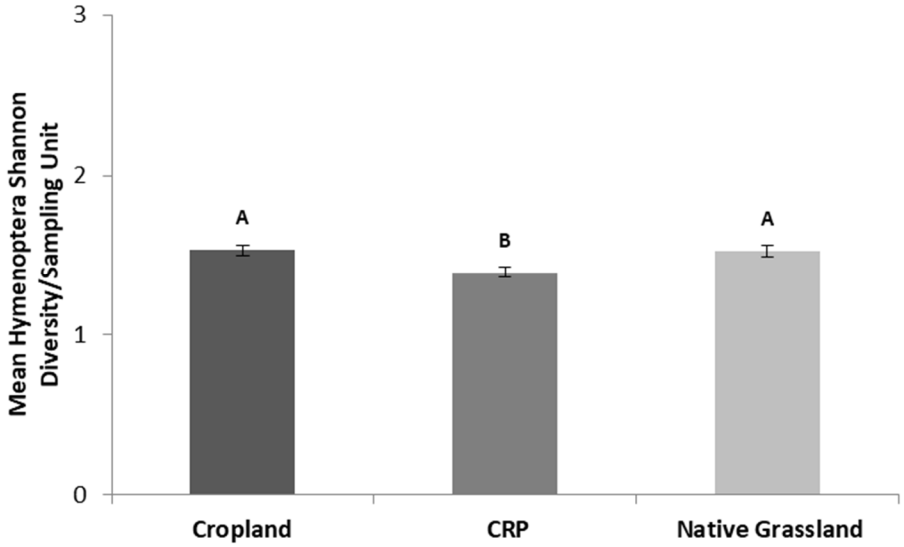
b.


Mean Total Pollinator Shannon Diversity/Sampling Unit
3
2
1
0
A
B
A
Cropland
CRP
Native Grassland

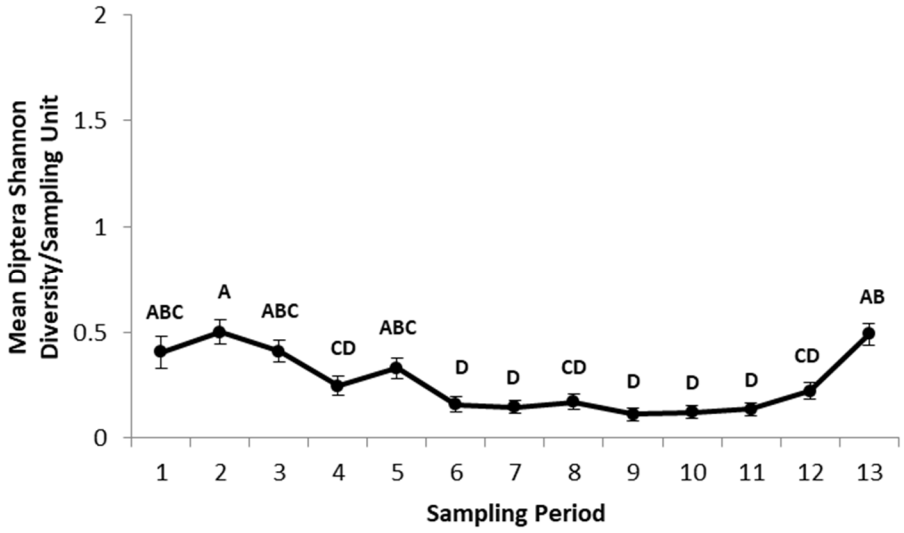
c.


Mean Total Hymenoptera Shannon Diversity/Sampling Unit
3
2
1
0
E
BCD
CD
ABCD
ABC
D
CD
ABCD
ABCD
ABCD
ABCD
AB
A
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

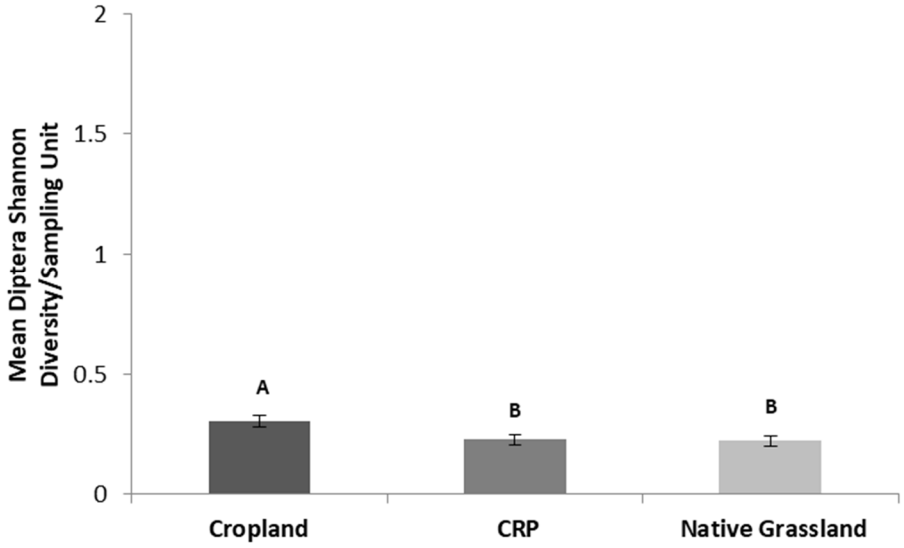
d.


Mean Hymenoptera Shannon Diversity/Sampling Unit
3
2
1
0
A
B
A
Cropland
CRP
Native Grassland

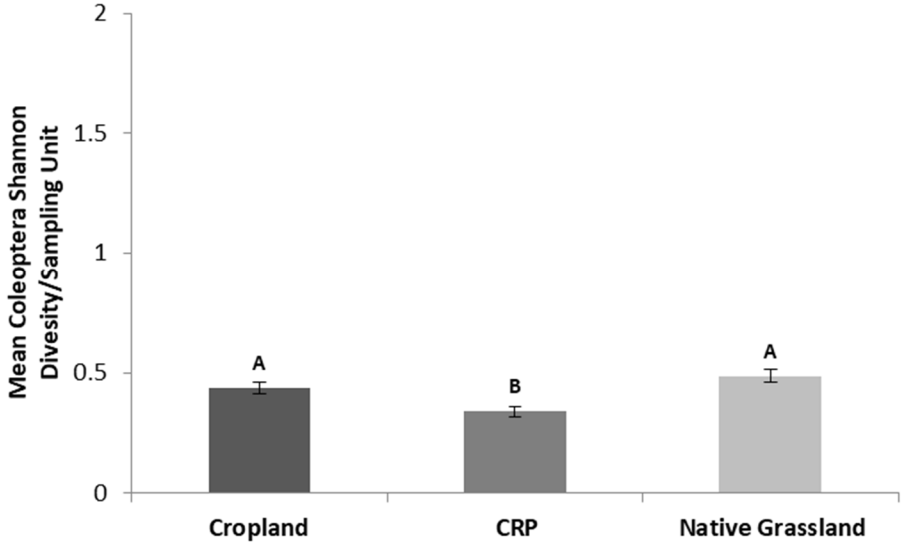
e.


Mean Diptera Shannon Diversity/Sampling Unit
2
1.5
1
0.5
0
ABC
A
ABC
CD
ABC
D
D
CD
D
D
D
CD
AB
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

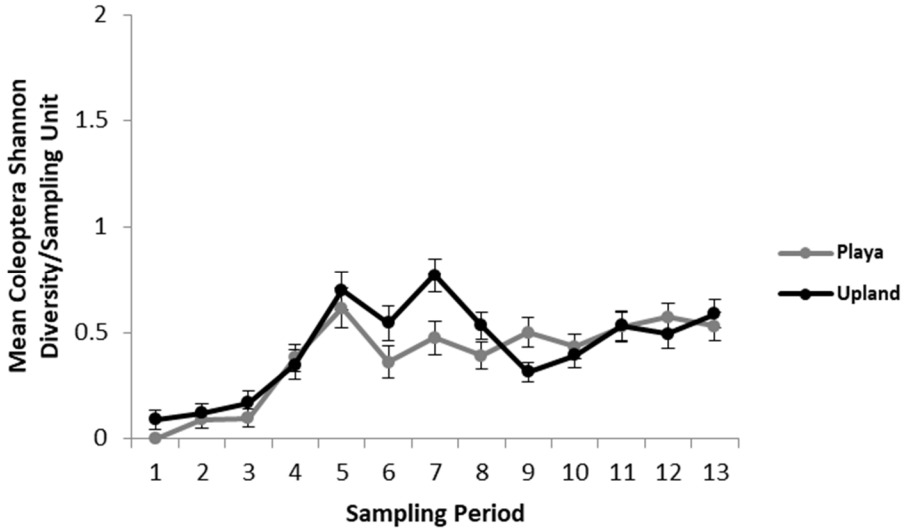
f.


Mean Diptera Shannon Diversity/Sampling Unit
2
1.5
1
0.5
0
A
B
B
Cropland
CRP
Native Grassland

g.


Mean Coleoptera Shannon Divesity/Sampling Unit
2
1.5
1
0.5
0
A
B
A
Cropland
CRP
Native Grassland

h.


Mean Coleoptera Shannon Diversity/Sampling Unit
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

i.

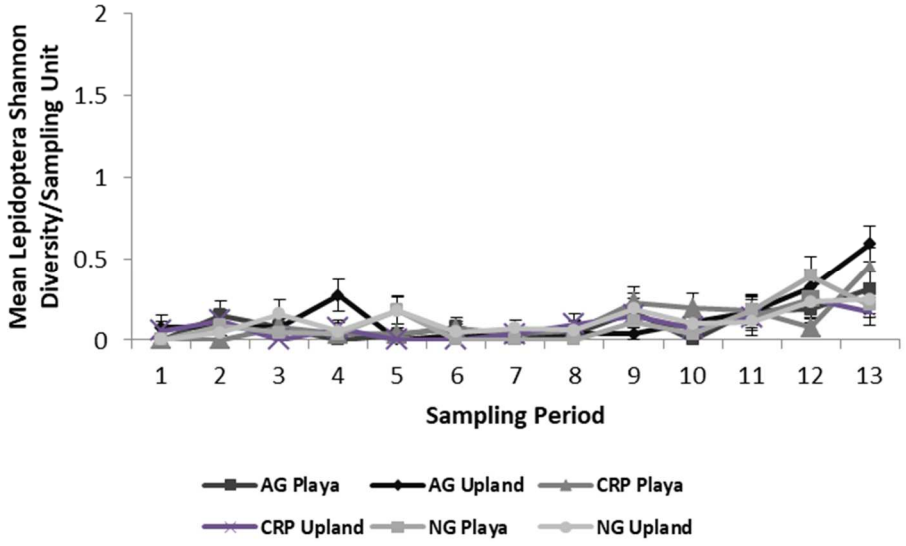
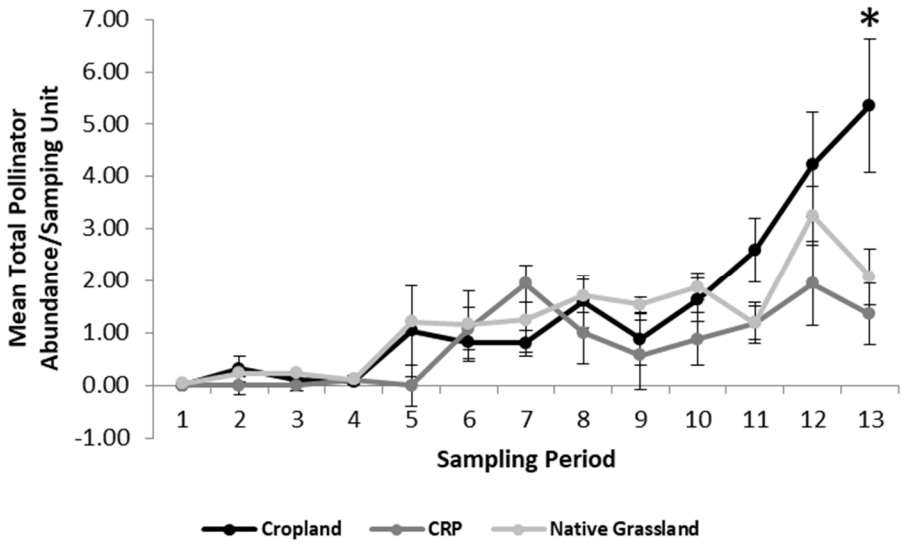
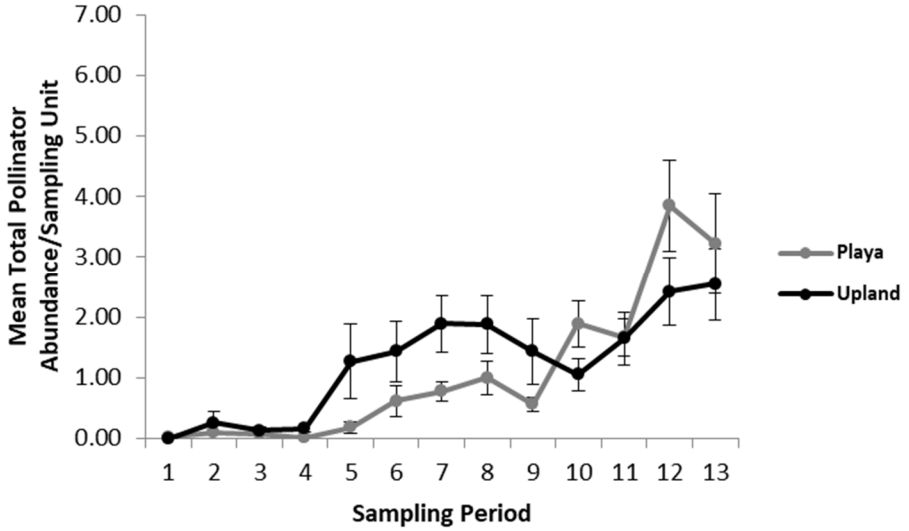

Mean Lepidoptera Shannon Diversity/Sampling Unit
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
AG Playa
AG Upland
CRP Playa
CRP Upland
NG Playa
NG Upland

Figure III.8. Effects of sampling period, land use, and land type on pollinator abundance for specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between land use or land type within a sampling period interaction, it is designated with an asterisk (*). Total season land uses and sampling periods with the same letter are not statistically different. a.) Total pollinator abundance – sampling period x land use, b.) Total pollinator abundance – sampling period x land type, c.) Hymenoptera abundance – sampling period x land type, d.) Hymenoptera abundance – land use, e.) Diptera abundance – sampling period x land use, f.) Diptera abundance – sampling period x land type, g.) Coleoptera abundance – sampling period x land use, h.) Lepidoptera abundance – sampling period.

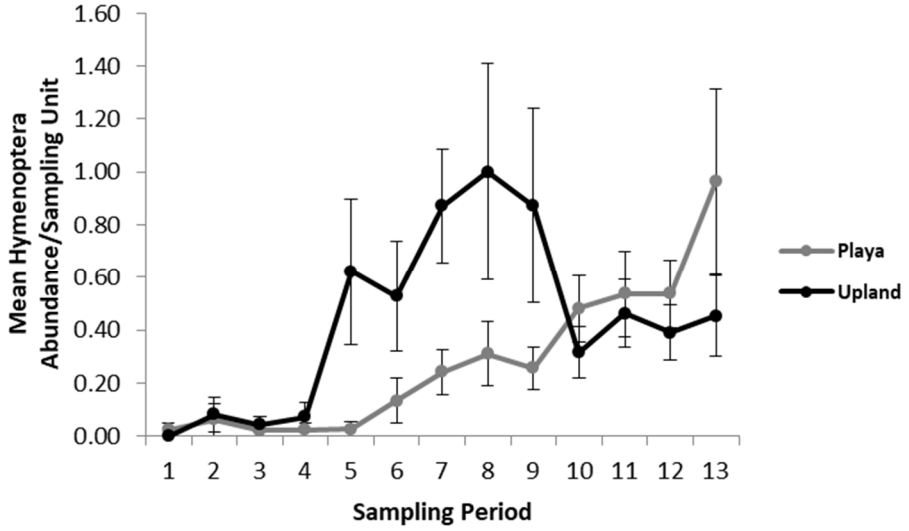
a.



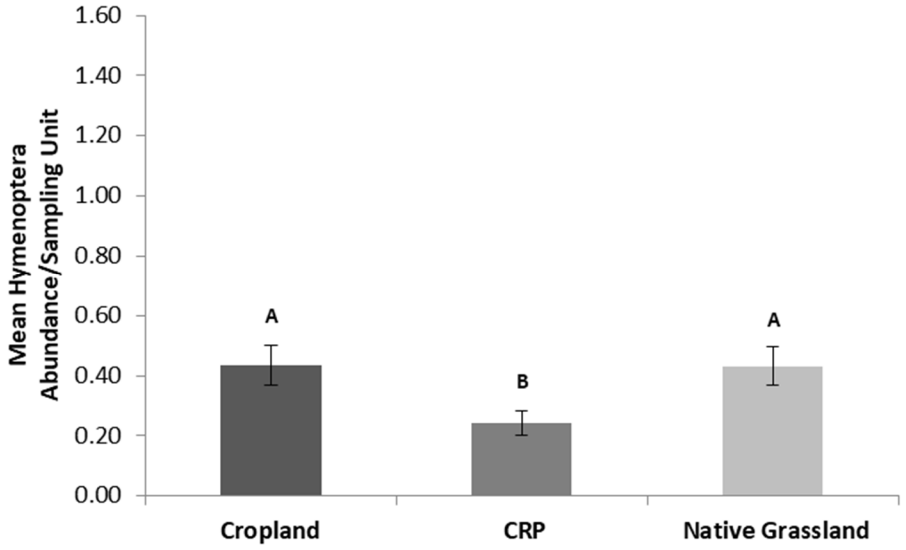
b.


Mean Total Pollinator Abundance/Sampling Unit
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

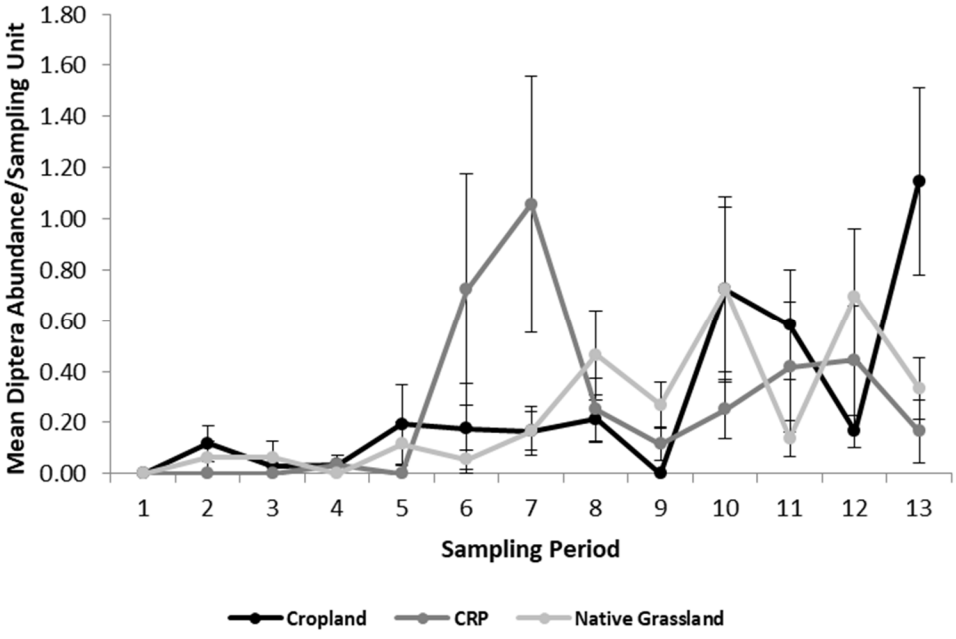
c.


Mean Hymenoptera Abundance/Sampling Unit
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

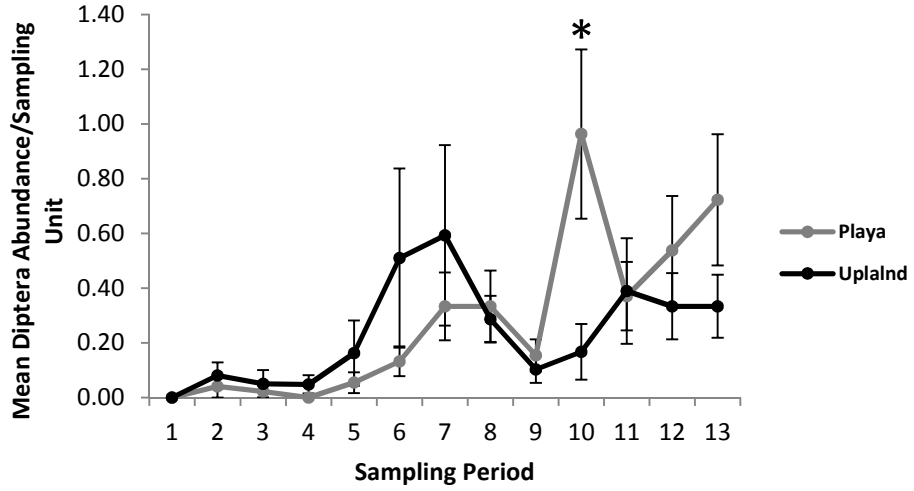
d.


Mean Hymenoptera Abundance/Sampling Unit
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A
B
A
Cropland
CRP
Native Grassland

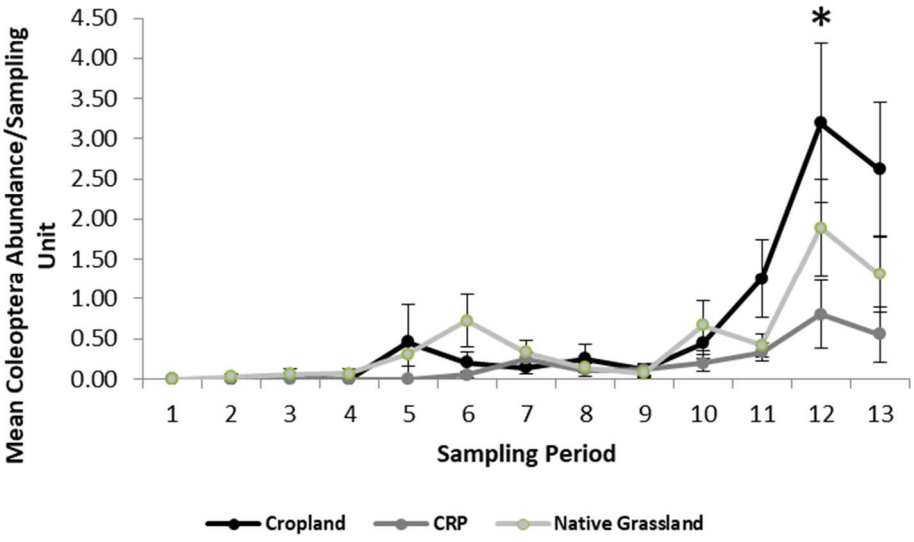
e.


Mean Diptera Abundance/Sampling Unit
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Cropland
CRP
Native Grassland

f.


Mean Diptera Abundance/Sampling Unit
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Uplalnd

g.


Mean Coleoptera Abundance/Sampling Unit
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Cropland
CRP
Native Grassland

h.

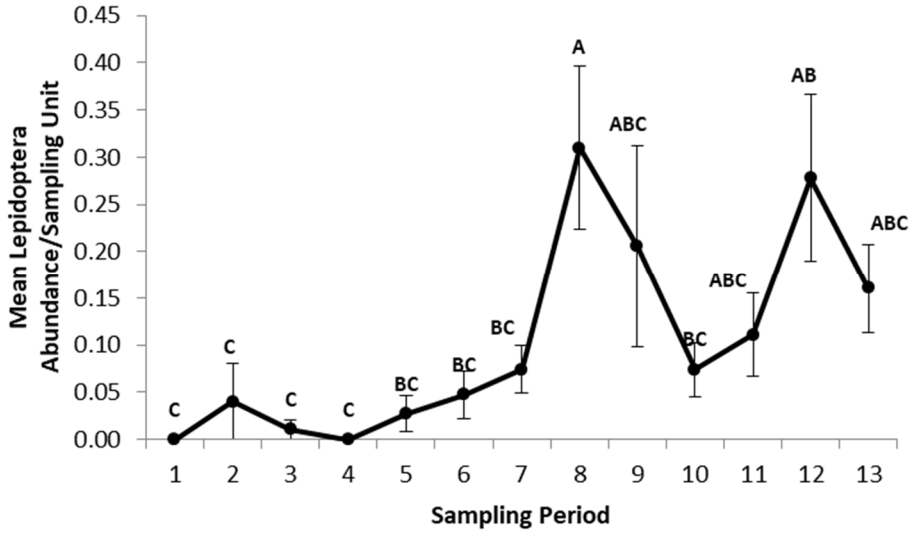
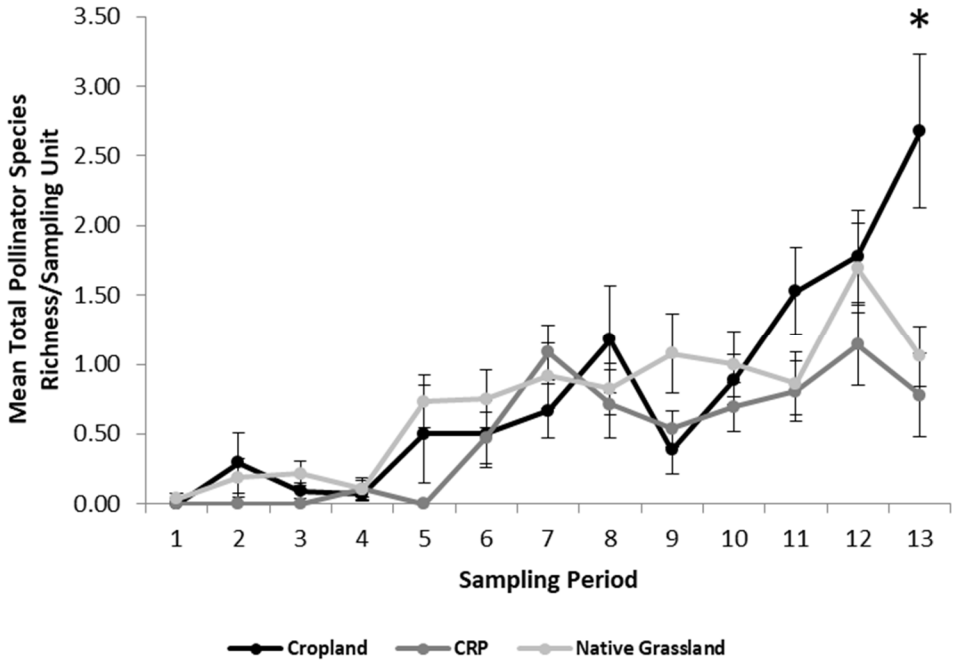
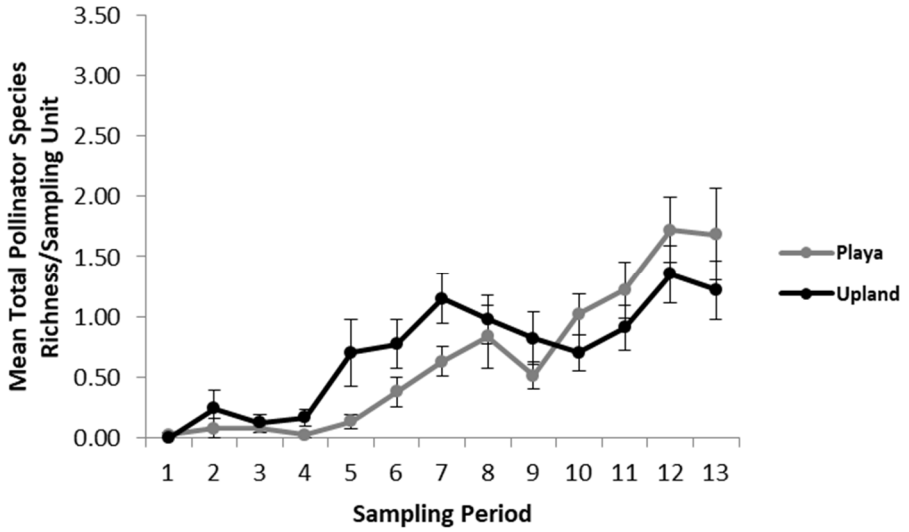

Mean Lepidoptera Abundance/Sampling Unit
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
C
C
C
C
BC
BC
BC
A
ABC
BC
ABC
AB
ABC
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

Figure III.9. Effects of sampling period, land use, and land type on pollinator species richness for specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between land use or land type within a sampling period interaction, it is designated with an asterisk (*). Total season land uses and sampling periods with the same letter are not statistically different. a.) Total species richness – sampling period x land use, b.) Total species richness – sampling period x land type, c.) Hymenoptera species richness – sampling period x land type, d.) Hymenoptera – land use, e.) Diptera species richness – sampling period x land use, f.) Diptera species richness –sampling period x land type, g.) Coleoptera species richness – sampling period x land use, h.) Lepidoptera species richness – sampling period.

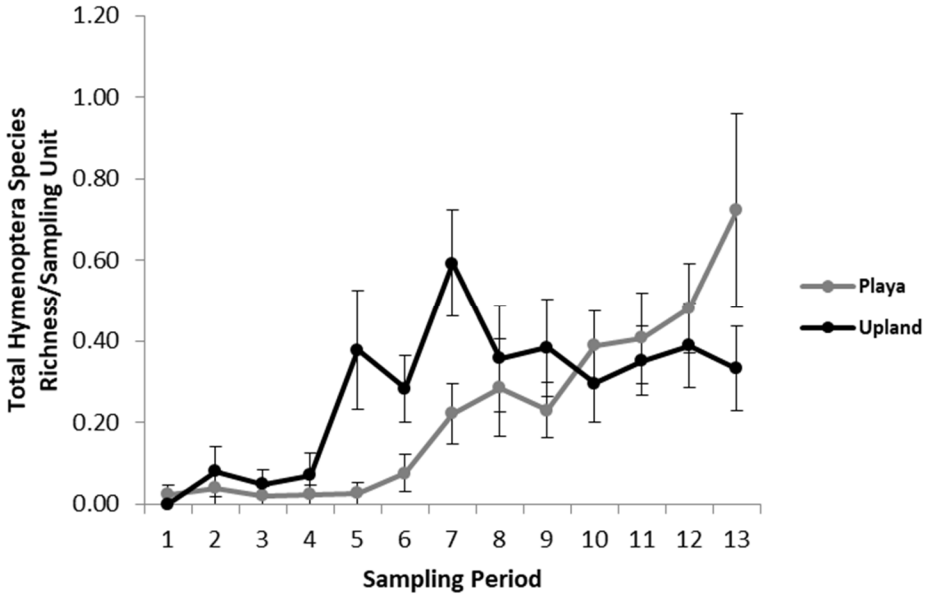
a.



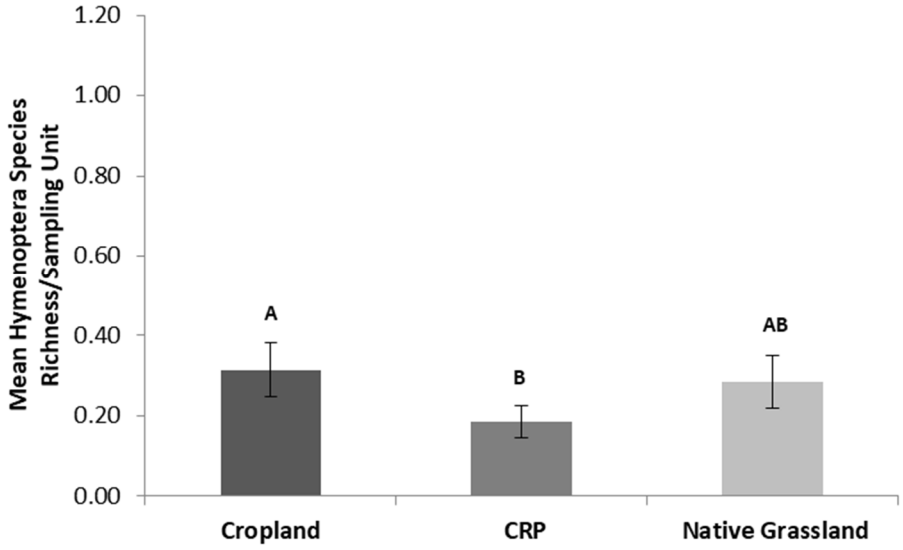
b.


Mean Total Pollinator Species Richness/Sampling Unit
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

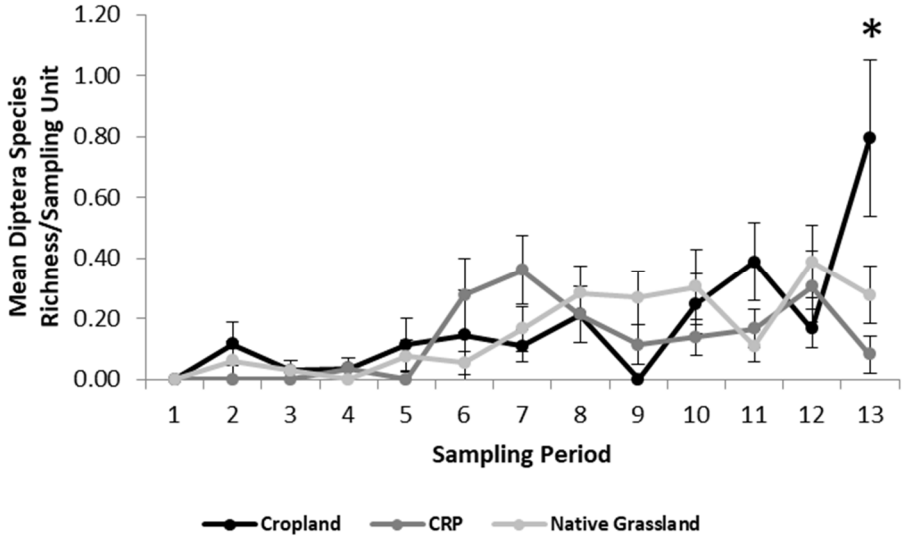
c.


Total Hymenoptera Species Richness/Sampling Unit
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

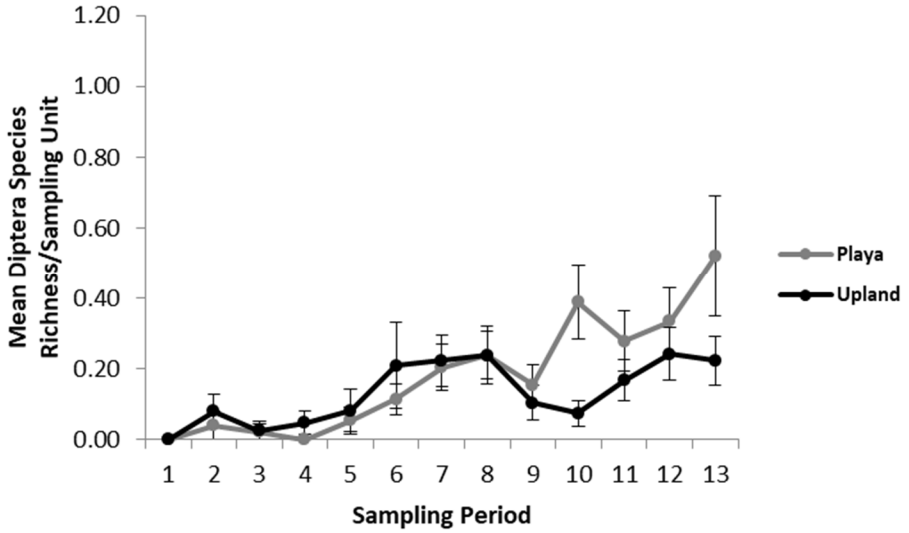
d.


Mean Hymenoptera Species Richness/Sampling Unit
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A
B
AB
Cropland
CRP
Native Grassland

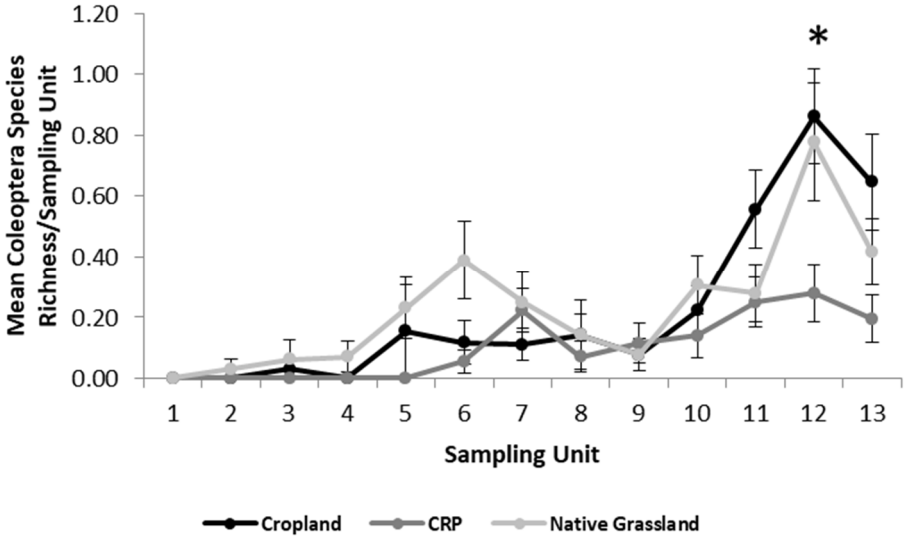
e.


Mean Diptera Species Richness/Sampling Unit
1.20
1.00
0.80
0.60
0.40
0.20
0.00
*
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Cropland
CRP
Native Grassland

f.


Mean Diptera Species Richness/Sampling Unit
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
Playa
Upland

g.


Mean Coleoptera Species Richness/Sampling Unit
1.20
1.00
0.80
0.60
0.40
0.20
0.00
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Unit
Cropland
CRP
Native Grassland

h.

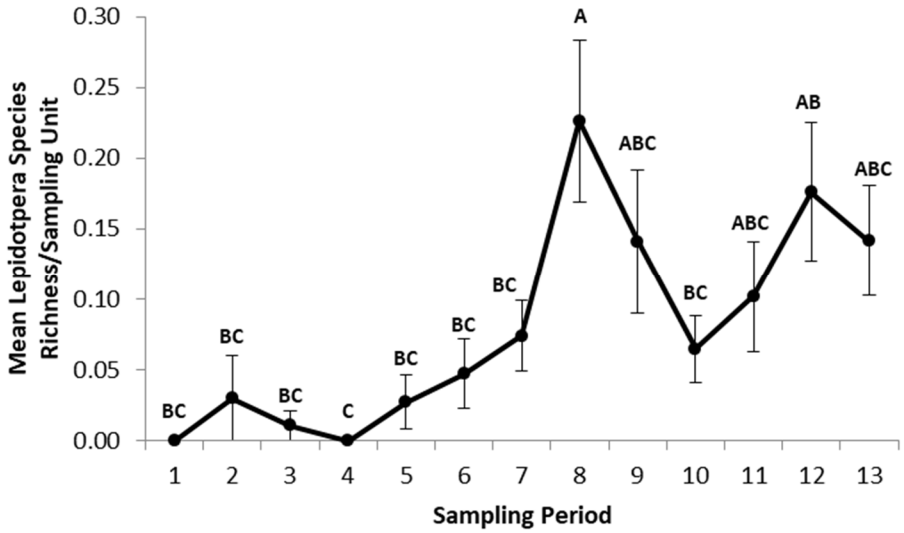
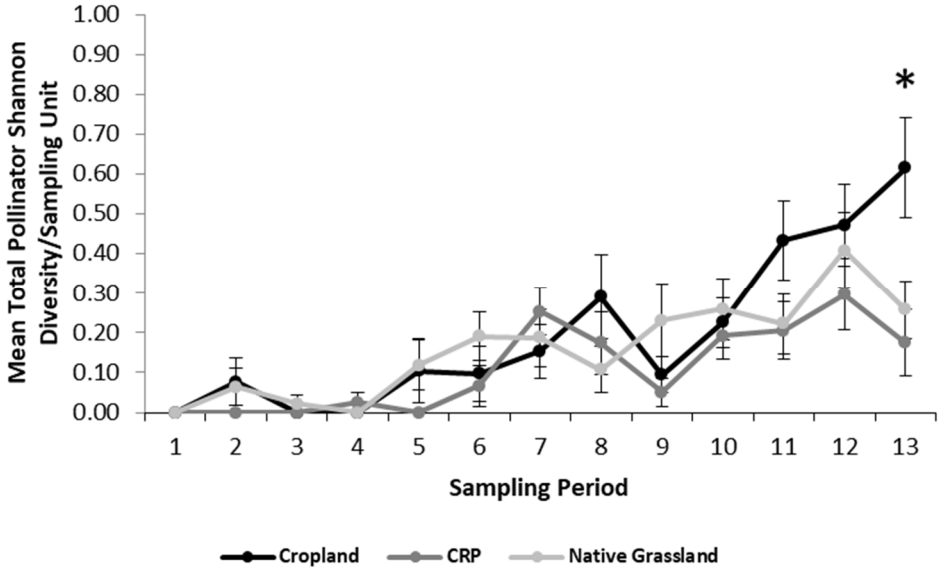
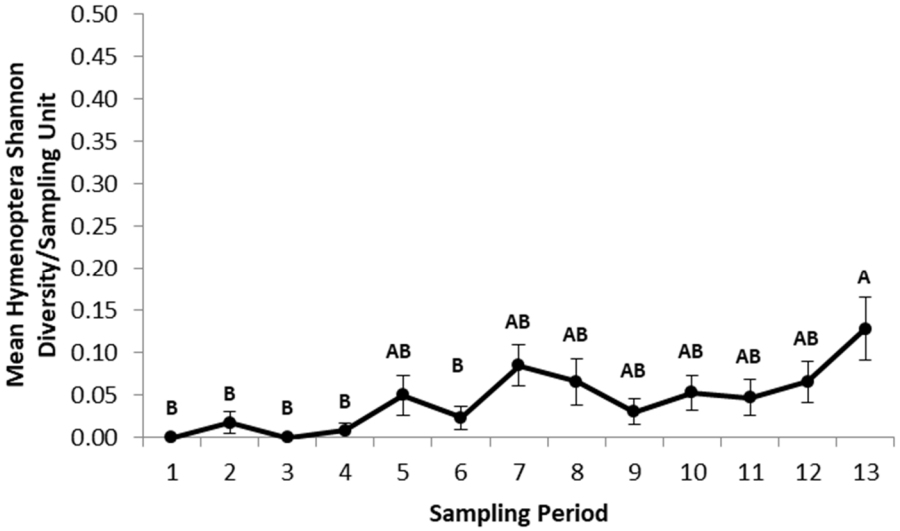

Mean Lepidotpera Species Richness/Sampling Unit
0.30
0.25
0.20
0.15
0.10
0.05
0.00
BC
BC
BC
C
BC
BC
BC
A
ABC
BC
ABC
AB
ABC
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period

Figure III.10. Effects of sampling period, land use, and land type on pollinator Shannon-Wiener diversity for specimens collected with targeted sweep netting in 2013-2014. Specimens were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Sampling period dates are included in Table II.1. If there is a difference between land use or land type within a sampling period interaction, it is designated with an asterisk (*). Total season land uses and sampling periods with the same letter are not statistically different. a.) Total pollinator Shannon-Wiener diversity – sampling period x land use, b.) Hymenoptera Shannon-Wiener diversity – sampling period, c.) d.) Diptera Shannon-Wiener diversity – sampling period x land use x land type, e.) Coleoptera Shannon-Wiener diversity – sampling period, f.) Coleoptera Shannon-Wiener diversity – land use.

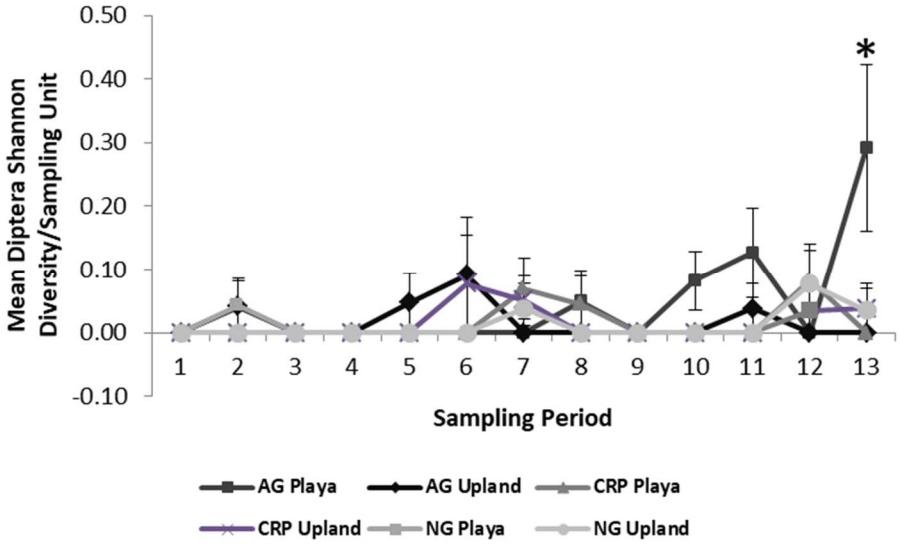
a.



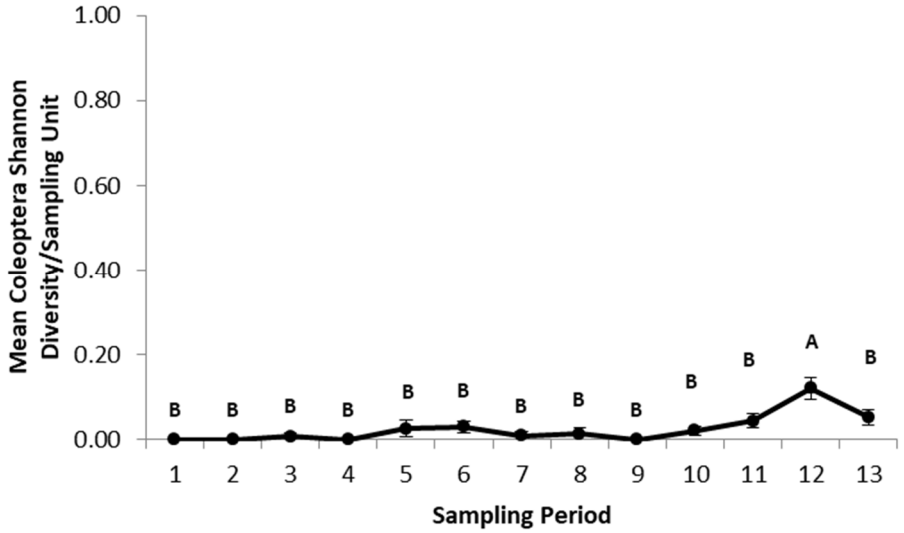
b.


Mean Hymenoptera Shannon Diversity/Sampling Unit
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
B
B
B
B
AB
B
AB
AB
AB
AB
AB
AB
A
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period

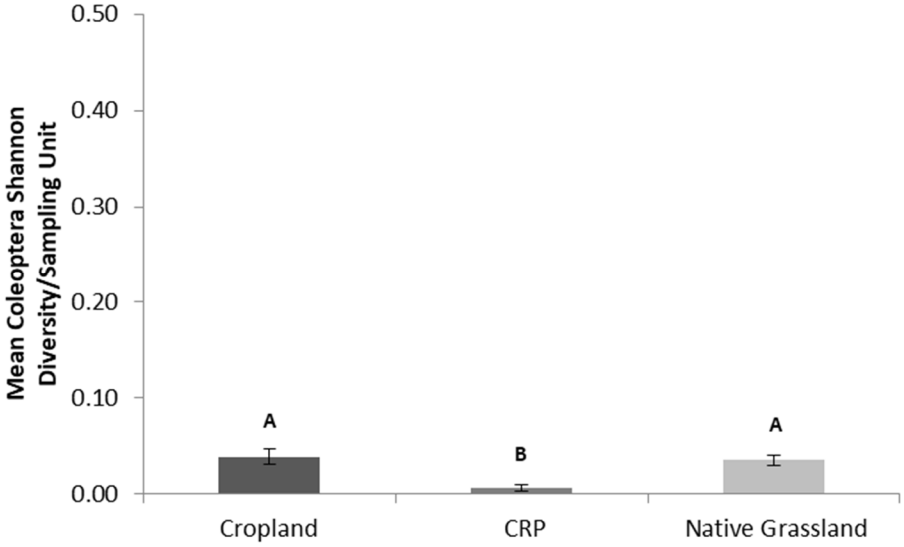
c.


Mean Diptera Shannon Diversity/Sampling Unit
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
*
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period
AG Playa
AG Upland
CRP Playa
CRP Upland
NG Playa
NG Upland

d.


Mean Coleoptera Shannon Diversity/Sampling Unit
1.00
0.80
0.60
0.40
0.20
0.00
B B B B B B B B B B B A B
1 2 3 4 5 6 7 8 9 10 11 12 13
Sampling Period

e.


Mean Coleoptera Shannon Diversity/Sampling Unit
0.50
0.40
0.30
0.20
0.10
0.00
A
B
A
Cropland
CRP
Native Grassland

# CHAPTER IV

## EFFECTS OF FLORAL COMPOSITION AND VEGETATION CHARACTERISTICS OF CROPLAND, CRP, AND NATIVE GRASSLANDS ON POLLINATOR COMMUNITIES IN THE LLANO ESTACADO


## ABSTRACT

One of the goals of the White House's Memorandum on Creating a Federal Strategy to Promote the Health of Honeybees and other Pollinators was to increase the value of pollinator habitat in USDA conservation programs, specifically the Conservation Reserve Program (CRP). The CRP retires highly erodible cropland and places it in permanent cover. The Southern High Plains (SHP) of Texas had one of highest concentrations of CRP contracts in the country and was identified as an area where the demand for pollination service may exceed availability in the future. Therefore, we evaluated vegetation characteristics of the three primary SHP land uses, croplands, CRP, and native grasslands, and their embedded playas to assess the effectiveness of CRP at providing pollinator habitat. Characteristics included percent grass cover, non-flowering forb cover, flowering forb cover, bare soil, duff cover, embedded litter cover, woody litter cover, canopy gap, mean vegetation height, and vegetation height variance. AIC model selection and path analysis showed that land use driven by percent grass and duff cover

within each land use were the primary drivers of pollinator abundance and richness. Of the three land uses, CRP had the most adverse effect on total pollinator abundance and richness, although main effects were small. Partial redundancy analysis (pRDA) determined that land type (wetland, upland), land use, and vegetation characteristics explained only 18.5% of the variation in pollinator abundance and richness. Pollinator use of upland sites over wetlands explained most of this variation based on vane trap data. However, bipartite graphs constructed using sweep net data showed that pollinators frequently foraged on wetland plants, suggesting that sweep net data gives us a more accurate account of the plants on which pollinators are feeding. Analyses of the topographic structure of plant-pollinator interaction networks of each SHP land use determined that pollinator communities are poorly connected with low nestedness and low to moderate asymmetry, meaning they could be susceptible to species loss from disturbance. Implementing buffers strips around playas seeded with native grasses and flowering forbs could serve as important refugia for pollinators and protect cropland playas from sedimentation. CRP could be improved by creating seed mixes that include native grasses and native flowering forbs to replace existing non-native grasses to enhance availability of nesting sites for solitary bees and expand floral resources. Native grasses in CRP uplands will also allow for a more natural hydrology of the embedded playas and encourage growth of wetland plants.

## INTRODUCTION

One of the major threats to native pollinator populations and the persistence of plants on which they feed is habitat loss (Cane and Tepedino 2001, Steffan-Dewenter et al. 2005, Council 2007, Potts et al. 2010, Hadley and Betts 2012), primarily from

intensification of land use for agricultural purposes (Winfree et al. 2009). In response to growing concern for how a decline in pollination service could affect the agricultural economy (Morse and Calderone 2000, Steffan-Dewenter et al. 2005, Calderone 2012a), the U.S. White House issued a Memorandum on Creating a Federal Strategy to Promote the Health of Honeybees and other Pollinators (The White House 2014). One of the overriding goals was to increase the quality of pollinator habitat in the US Department of Agriculture's conservation programs, including the Conservation Reserve Program (CRP) (The Pollinator Health Task Pollinator Health Task Force 2015). The Report of the Pollinator Health Task Force further outlined goals to increase pollinator benefit from CRP land and to double the area enrolled in pollinator initiatives to 80,937 hectares by 2018 (The White House 2016b). The CRP is the largest government conservation program in the United States (Stubbs 2014), and over 9.63 million ha are currently enrolled (Farm Service Agency 2017). Participating landowners receive rental payments to take highly erodible or environmentally sensitive land out of production in exchange for establishment of permanent vegetation cover for 10 or more years (Stubbs 2014).

The Southern High Plains (SHP) is one of the most intensively cultivated regions in the Western Hemisphere (Bolen et al. 1989). Because of the intensive agriculture and high erosion potential, the Texas High Plains receives considerable funding through the CRP (Farm Service Agency 2017). The area targeted in this study, nine counties in the SHP of Texas, had some of the highest concentrations of CRP enrollment in the country (Farm Service Agency 2017). This area was also targeted as a region at-risk of inadequate pollination service (Koh et al. 2016). Although many of the world's major food crops are not directly dependent upon insect pollination, especially many of those

raised in the SHP (Chapter III), 75% benefit to some degree, especially vegetable and fruit crops (Klein et al. 2007, Lautenbach et al. 2012, Hanley et al. 2015). Pollinators also serve an essential role in maintaining native grassland and rangeland health (Black et al. 2011, Gilgert and Vaughan 2011) which is critical to the cattle industry in this region (Fleischner 1994).

Playa wetlands are a defining landscape characteristic of the SHP (Smith 2003). They are shallow, depressional, recharge wetlands characteristic of prairie and semi-arid habitats formed and maintained by wind, waves, and dissolution (Smith 2003). In an area of intensive agriculture, they are the primary source of biodiversity in the region (Haukos and Smith 1994). Many species of wildlife in the SHP are dependent upon playas because they comprise the majority of the remaining native habitat (Haukos and Smith 1997). Wetland flowering forbs have potential to serve as a source of forage for pollinators. These wetlands, however, are under threat from watershed erosion and rural and urban development (Smith 2003). Johnson et al., (2012) determined that 60% of original playas were lost from the SHP between 1970 and 2008 from erosion caused sedimentation fill and loss of visible depression. As sedimentation alters playa hydroperiods and shifts floral composition from perennials to predominantly annuals (Smith and Haukos 2002), it is important to understand what wetland flowers pollinators feed on to help land managers devise conservation strategies for these critical habitats.

*Characteristics of Land Use and Pollinator Habitat*

Although habitat loss (Council 2007, Potts et al. 2010) and small patch size (Kremen et al. 2004, Menz et al. 2011) are some of the primary threats to pollinator

persistence (Council 2007), some species are more sensitive to habitat characteristics such as percent vegetation cover and percent rockiness than the size of the habitat fragment (Donaldson et al. 2002). The fundamental habitat needs of pollinators include bare patches of ground with sun exposure, vegetation litter for cover and nesting materials (Delaplane 2000, Gilgert and Vaughan 2011, Black et al. 2014), and proximity to small rocks to enhance warming of the nest (Brockman 1979). Invertebrate pollinators need abundant and diverse populations of annual and perennial flowers across the entire growing season and varying sizes of bare soil exposed to the sun for ground nesters to complete life history requirements (Delaplane 2000, Gilgert and Vaughan 2011). Dead wood, pithy plant stems, and ground litter and burrows provide additional nesting habitat for above ground nesting bees (Delaplane 2000, Vaughan and Black 2008, Gilgert and Vaughan 2011). More specialized pollinator nesting requirements include soils with appropriate texture to maintain tunnel structure without being too compacted for the insect to excavate (Brockman 1979), spaces under rocks, old rodent burrows and holes in dead wood (Cane and Tepedino 2001). A balance of disturbed and undisturbed areas is favorable for many pollinators, especially bees (Gilgert and Vaughan 2011). Disturbed areas promote varying successional stages of flowering forbs and maintain habitat diversity (Gilgert and Vaughan 2011). Undisturbed areas encourage nesting (Delaplane 2000).

Donaldson et al. (2002) demonstrated that insect pollinators were more sensitive to habitat characteristics than to fragment size and that vegetative cover was a more influential determinant of insect species diversity than area. Habitats with diverse horizontal and vertical vegetation structure may have enhanced pollination services

through architectural complementarity where various pollinators work at different plant heights and sheltered areas (Blüthgen and Klein 2011). Although there is research that documents the habitat requirements for many pollinators (Brockman 1979, Neal 1998, Delaplane 2000, Cane and Tepedino 2001, Gilgert and Vaughan 2011), there is little information on architectural complementarity, or how varying heights of plants may influence pollinator diversity or pollination effectiveness (Blüthgen and Klein 2011).

*Plant-Pollinator Interaction Networks*

Estimating diversity is an important tool in determining the health of an ecosystem (Magurran 1988). Pollinator diversity is essential for maintaining biodiversity in ecosystems (Willmer 2011a) and plays a central role in the basis of energy rich food webs (Kearns et al. 1998). Pollinator diversity, however, cannot be considered independent of plant diversity because of the mutualistic relationship between plants and pollinators (Kearns and Inouye 1997, Tylianakis et al. 2010). Plant-pollinator interaction networks incorporate pollinator diversity and the flowers on which they visit, and can be used to estimate the stability and robustness of pollination services in an ecosystem (Memmott et al. 2004, Fontaine et al. 2006, Menz et al. 2011, Astegiano et al. 2015). Plant-pollinator interaction networks are the collective matrix of plants and their pollinator species, and are often illustrated as pollination webs with bipartite graphs (Dormann et al. 2009, Ramos-Jiliberto et al. 2009, Dormann et al. 2017) which are similar to food webs (Martinez 1992, Dunne et al. 2002a, Dunne et al. 2002b).

This method of organizing plant-pollinator interactions identifies specific plants on which pollinators are visiting and potentially providing pollination service. Bipartite

graphs also help define plant and pollinator species as either generalists or specialists. Generalists interact with and form foraging linkages with many species and specialists interact with and form foraging linkages with one or only a few species (Bosch et al. 2009, Dorado et al. 2011). The manner in which these mutualistic networks are structured is important for understanding how plant and pollinator species may have coevolved (Petanidou et al. 2008, Bosch et al. 2009). These networks may also reveal the potential resilience of populations to species loss and extinction from anthropogenic effects (Elmqvist et al. 2003, Memmott et al. 2004). Interactions within this network structure could also be a key to understanding successful habitat conservation and restoration. Reconstructing the relationships between plants and pollinators may help restoration success. These interactions may also be important for understanding the persistence of re-established plant populations (Neal 1998, Potts et al. 2003b, Menz et al. 2011, Devoto et al. 2012).

Most research suggests that plant-pollinator interaction networks share the same structure: they are nested and asymmetric (Bascompte et al. 2003, Vázquez and Aizen 2004, Bascompte et al. 2006, Chacoff et al. 2012), and most have more pollinator species than plant species (Dicks et al. 2002, Memmott et al. 2004, Alarcon et al. 2008, Bosch et al. 2009). Nestedness is a measure of the level of organization in a network where specialized species interact with a core group of generalist species (Bascompte et al. 2003, Bosch et al. 2009, Chacoff et al. 2012). These generalist/specialist interactions are characterized as asymmetric (Bascompte et al. 2003, Vázquez and Aizen 2004, Bascompte et al. 2006, Petanidou et al. 2008) because most generalist plants interact with insect specialists and specialized plants are visited by insect generalists (Waser 2006).

This asymmetry buffers the effects of species loss on pollination service (Memmott et al. 2004). Nestedness and asymmetry appear to provide resilience to disturbance (Memmott et al. 2004) and reduce interspecific competition (Bastolla et al. 2009) within a pollination system.

Connectance is the proportion of all possible interactions of plants and pollinators within a network (Dunne et al. 2002a, Bosch et al. 2009, Tucker and Rehan 2016) and a measure of specialization or generalization in networks (Fründ et al., 2010). It is used to measure the ability of a network to withstand species loss (Tucker and Rehan 2016), and higher connectance can indicate a more robust pollinator community (Dunne et al. 2002b). Understanding the structure of pollination networks may help inform restoration strategies and the strength of the networks to resist or recover from disturbance and habitat loss (Jordano 1987).

Our first objective was to determine the habitat characteristics of native grasslands, croplands, and CRP within the study area and their influence on pollinator abundance, richness, and diversity. These characteristics included percent grass, non-flowering forb, flowering forb, bare soil, duff, embedded litter, woody litter, canopy gap and vegetation height mean and variance of playas and uplands. We will determine if land use overall is the primary influence on pollinator communities or if a specific habitat characteristic or a combination of characteristics influence pollinator abundance, species richness, and diversity. Through analysis of variance, we determined which vegetation characteristics differ between land uses and land type. Using path analysis, we will determine the best explanatory model of vegetation characteristics and land use that explains pollinator abundance and species richness. Partial redundancy analysis was used

to indicate the amount of variation in the pollinator community explained by land use, land type (playa vs. upland) and vegetation characteristics. Our second objective was to identify specific plants on which pollinators forage within each land use and determine how pollinators are using playa wetlands, and wetland plants that are potentially important to pollinators. We will construct plant-pollinator interaction bipartite graphs to visualize the structure of pollination interaction networks. The bipartite graphs will allow us to determine the most important flowers for pollinators and illustrate important mutualistic associations within each land use. We will determine the stability and robustness of plant-pollinator interaction networks within each land use by calculating nestedness, asymmetry, and connectance. Finally, based on our findings, we will make recommendations to improve CRP seed mixes and how CRP can be managed to create pollinator habitat in the SHP. These recommendations will address the goals outlined in the White House's Pollinator Health Strategy (Pollinator Task Pollinator Health Task Force 2015).

## MATERIALS AND METHODS

### *Study Location and Site Selection*

Data for this analysis were from the same playas on privately owned sites located in nine counties in the Panhandle of and West Texas (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher) that encompassed approximately 2,353,522 ha (U.S. Census United States Census Bureau 2007) (Figure IV.1) as described in Chapter III. We selected these sites for our study because they were used in several previous studies of playas except native grassland sites in Carson and Hockley Counties,

a CRP site in Castro County, and cropland site in Bailey County, and were equipped with weather stations (Chapter III). We had three sites in each county that represented each land use; cropland, CRP, and native grasslands. Each location had an embedded playa, for 27 watershed-sampling sites. Based on 2014 estimates producers planted 809,978 ha of cotton, winter wheat, corn, sorghum, or soybeans in the nine counties (National Agricultural Statistics Service 2016) and 292,564 ha was in CRP with over $ 25,624,627 million in rental payments for the fiscal year (Farm Service Agency 2017). Cattle grazed most uncultivated native grassland areas (shortgrass prairie). Playa area within the study site was estimated at 68,742 ha in 1992 (Haukos and Smith 1994). The mean monthly temperature range for 2013 between April and September was 12.6°C – 25.9°C. The minimum monthly temperature range was 2.6°C – 18.5°C with a maximum range of 22.5°C – 33.8°C and average monthly precipitation of 0.5 mm – 77.7 mm. For 2014, the mean monthly temperature range was 14.3°C – 25.6°C. The minimum monthly temperature range was 4.6°C – 18.9°C with a maximum range of 24°C – 33.4°C and average monthly precipitation of 13.7 mm – 129.8 mm (Menne et al. 2016a).The sampling area was in a drought when data collection began in 2013 which persisted until 2014 (National Drought Mitigation Center 2017).

*Methods*

The field season ran from April – September in 2013 and 2014 for 26 weeks with 13 sampling periods. We grouped sampling sites according to geographic similarities, generally by county, and we sampled a reference (native grassland – never plowed), CRP, and cropland site on the same day, when conditions permitted, between 0800 and 1800 for consistency of weather and other environmental factors (Chapter III). Invertebrate

sampling occurred on a bi-weekly rotation to account for weather and seasonal variations and ephemeral blooming periods of flowers. Although what defines a pollinator can vary from geographic location and the floral composition of the landscape, for the sake of simplicity, we will refer to all invertebrates as pollinators (Chapter III).

We established six permanent sets of parallel belt transects, each 25 m long by 2 m wide separated by approximately 10 m, three in the catchment and three in the playa (Figure IV.2). One transect in each set was used to collect vegetation data and place the invertebrate traps, and the other was used to collect plant-pollinator data with sweep nets. Transects were placed based on a random azimuth bearing from the center of the playa. Upland transects were placed at least 25 m from the edge of the playa (Chapter II). Aerial maps determined playa edge, and we confirmed it visually on the ground (Luo et al. 1997). Each land use in each county was represented by upland and wetland sampling units. Three traps were pooled in the upland and three traps in the playa to compare experimental units.

*Blue Vane Traps*

We collected the majority of potential pollinators with Springstar™ blue vane traps (Stephen and Rao 2005, 2007). They are a visual attractant and do not contain killing agents or additives such as water and soap (Stephen and Rao 2005). Traps were placed halfway down one of each set of transects (12.5 m) on a wooden post with a wire hangar adjusted so the traps were visible or in line with vegetation height. Traps were set out each day and collected the following day as close to 24 hours as possible. The time traps spent in the field was recorded in 15-minute intervals (Chapter III). Specimens from

each trap were packaged and stored frozen. Insects were identified to species when possible by Northern Prairie Wildlife Research Center (NPWRC) technicians and at Oklahoma State University by a technician and graduate student. We confirmed insect identification by consulting reference collections and with input from taxonomic specialists (Chapter II).

*Targeted sweep netting*

Targeted sweep netting linked pollinators with the specific plants they visit and on which they potentially feed. In the transect belt parallel to the transect containing the blue vane trap, pollinators were collected within 1 meter each side of the transect as they fed on flowers. A technician moved slowly up each transect and observed it for 6 minutes, "hunting" for foraging insects, targeting forb patches, and collecting pollinators as they visited specific plants. While handling and bagging invertebrates, the collector paused the timer then resumed after the insect was collected. Once the insect was bagged and the interaction recorded, observation for the next foraging insects commenced. Each specimen bag was labeled with the date, locality of pollinator, and the USDA plant database symbol of the plant on which it was captured. The plant associated with the pollinator was pressed and labeled with the date, locality, USDA database plant symbol, collector's name, and corresponding pollinator numbers or species when determined. Plant species were collected and preserved once. A database was populated with date, transect number, pollinator number, order, family, genus, species, USDA plant database code of associated plant, and photo number if one was taken. We confirmed plant identification with Oklahoma State University taxonomists.

*Vegetation Data Collection*

We conducted vegetation sampling three times during each field season; early season (May 19- June 1, 2013 and May 11-24, 2014), midseason (July 14-27, 2013 and July 6-19, 2014), and late-season (September 1-14, 2013 and August 31-September 13, 2014) in the 25 m transect belts containing blue vane traps. Sampling multiple times throughout the season allowed us to track seasonal shifts in the vegetation community. We collected vegetation composition and canopy data. We categorized plants as flowering forbs, non-flowering forbs, and graminoids. Non-flowering forbs were plants without a showy and obvious flower. Graminoids included all plants in the family Poaceae and *Eleocharis macrostachya* (USDA and NRCS 2017). Also, we measured vertical cover (Herrick 2009) for an assessment of pollinator habitat. We used a combination of line-point intercept and gap intercept methods. All data were collected off one 25-meter tape pulled taught against the ground, anchored on each end with rebar stakes. We measured canopy cover, species composition, vegetation height, canopy gap, and ground cover (Elzinga 1998, Herrick 2009). Groundcover measurements included percentage of bare soil, percentage of duff, embedded litter and woody litter cover. Duff is loose plant material that doesn't have a clear boundary between the soil layers and can be moved by wind (Herrick 2009). Embedded litter is a dense and compacted layer of vegetation that will disturb the underlying soil layer or leave an indention if removed (Herrick 2009). To measure canopy gaps, we used guidelines provided by Herrick et al. (2009). Along the length of the 25 m transect, we recorded the beginning and end of each canopy gap larger than 15 cm as viewed from standing height. We recorded the measurement to the nearest centimeter. Unattached litter is not canopy cover and was

included as part of the canopy gap. A canopy was defined when 50% of any 3 cm segment of the tape edge intercepts the plant canopy when viewed from above the canopy to the ground (Herrick et al., 2009). Vegetation height was recorded at 2 m intervals starting at 1, 10 cm from the edge of the tape.

*Land Use Vegetation Structure Analysis*

We conducted three-way ANOVAs to determine if there were significant effects of sampling period, land use, land type and interactions on percent flower cover, percent non-flowering forb cover, percent grass cover, percent bare soil groundcover, percent duff cover, percent embedded litter cover, percent woody litter cover, percent canopy gap, vegetation height mean, and vegetation height variance for early, mid, late, and all sampling periods combined (total). We used Tukey's post hoc analysis to determine differences between means for significant effects. ANOVAs and Tukey's post hoc analysis were performed in Minitab 17 (Minitab 17 Statistical Software 2010). Significance level was set at $\alpha = 0.05$.

We used path analysis (Wright 1934, Shipley 2016) to explore direct and indirect causal relationships between land use and vegetation characteristics on pollinator richness and abundance. We did this for each sampling period and all sampling periods combined. We chose path analysis to determine if land use effects were due to the land use itself as a whole, or if specific vegetation structure characteristics, or combinations thereof, mediated pollinator abundance and richness. We chose abundance and richness because these are components of diversity. Land use and vegetation factors may influence

pollinator abundance and richness differently, and we wanted to identify these influences as it could have important implications for conservation.

We constructed a full path model including land use, the vegetation characteristics we measured in the field, and pollinator richness and abundance to illustrate all possible causal relationships (Figure IV.3). There are two sets of relationships depicted in this model: direct effects and indirect effects (Suhr 2008, Shipley 2016). Direct effects are influences of each of the three land uses or vegetation characteristics on pollinator abundance and richness. Indirect effects are the influences of land use on pollinator abundance and richness measured by a specific vegetation characteristic of the land use, or a combination of vegetation variables. We tested the vegetation characteristics from the full model for correlation in R. Mean vegetation height and vegetation height variance were obviously correlated ($r = 0.696$). The curved two-way arrow in the input path diagram indicates the correlation between variables (Figure IV.3). Although Kruess and Tscharntke (2002) and Ryder et al. (2005) found that vegetation height is a primary determiner of variation in insect diversity among habitats, mean vegetation height was excluded from the analysis because vegetation height variance is potentially a more useful measure than vegetation height mean when considering architectural complementarity (Blüthgen and Klein 2011) in pollination systems. From the full model, we constructed possible explanatory models by selecting a vegetation type (grass, non-flowering forb, flower), a ground cover (soil, duff, embedded litter, or woody litter), and canopy gap or vegetation height variance. Candidate model 1 includes all variables that were not eliminated because of correlation. Model 2 includes only explanatory variables without land use effects. Model 3 is land use only, and model 4 is the null model. Models

5-55 were determined *a priori* by including combinations of specific habitat variables that we determined would best characterize each land use or combination of vegetation characteristics that contribute to pollinator habitat. Some models included land use and others excluded land use so we could test if vegetation characteristics alone were a stronger influence than land use. We conducted two analyses of abundance and two of species richness for each vegetation sampling period (early, mid, late and total); one comparing CRP to native grassland and one comparing CRP to cropland for a total of 16 analyses.

We used AIC model selection to determine the best model(s) from our list of 55 possible models (Table IV.1). We performed AIC model selection (Shipley 2013) using data from each sampling period and then the sampling periods combined and examined several indices to determine best model to fit the data. Structural equation modeling requires several statistical tests to determine the best model and best model fit (Hooper et al. 2008, Suhr 2008). We selected the Chi-Square test, (Hayduk et al. 2007, Hooper et al. 2008, Kline 2011), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), and comparative fit index (CFI) (Vulliamy et al. 2006, Hooper et al. 2008, Kline 2011). The threshold for best fit of models for $\chi^2$ should be small relative to degrees freedom, and as close to zero as possible with a p-value > 0.05 (Suhr 2008). Root mean square error of approximation (RMSEA) value thresholds vary from less than 0.07 (Steiger 2007, Hooper et al. 2008) to less than 0.03 (Hu and Bentler 1999, Hooper et al. 2008). Accepted thresholds for standardized root mean square residual (SRMR) are less than 0.08 (Hu and Bentler 1999, Hooper et al. 2008), and

comparative fit indices (CFI) should be greater than 0.90 (Hu and Bentler 1999, Suhr 2008) or 0.95. (Hooper et al. 2008)

When models with the best fit were determined using AIC, we used path analysis in R 3.3.3 using the lavaan package (Rosseel 2012) to create path diagrams and determine path coefficients. The path coefficient of each relationship is "the fraction of the standard deviation of the dependent variable for which the designated factor is directly responsible." (Wright 1934). Path coefficients indicate the strength of the effects of the independent variables on the dependent variables. The value of the effects is small if the value is less than 0.10, medium if the effect is around 0.30, and large if the value is greater than 0.50 (Suhr 2008).

*Community Data Analysis*

We used Canoco 5 (Ter Braak and Smilauer 2012, Smilauer and Lepš 2014) to construct a biplot of a partial redundancy analysis (pRDA) using vane trap and vegetation data combined. We wanted to isolate effects of land use, land type and vegetation type without the effects of geography (county). County was classified as a covariate (partialled-out) (Smilauer and Lepš 2014) so we could isolate effects of land use and land type without the effects of the northwest to southeast gradient of elevation and the southwest to northeast increase in precipitation (Smith 2003). Within Canoco, a detrended correspondence analysis (unconstrained unimodal ordination) resulted in ordination axes of 1 SD (turnover unit). For data with less than 3 SD, a linear method is recommended (Smilauer and Lepš 2014). Therefore, a partial redundancy analysis was appropriate because gradient lengths were short, and we incorporated a covariate into the

analysis (Potts et al. 2003a, Ter Braak and Smilauer 2012, Smilauer and Lepš 2014). These data were collected during early, mid, and late season to summarize variation in potential pollinator communities explained by vegetation characteristics over a growing season.

With data obtained from sweep netting, we constructed bipartite graphs illustrating the plant and floral visitor interaction networks for cropland, CRP, and native grasslands. We constructed a set with total potential pollinators collected, and a set with only bees. We used *networklevel* in the bipartite package in R 3.3.3. (Dormann et al. 2008) to create plant-pollinator interaction webs and measure ecological indices of the networks of each land use with total pollinators and with bees. We also recorded basic metrics such as the number of plant species and families, number of invertebrates, Shannon diversity of each network, and links per species to quantify the bipartite graphs. These indices are elementary and self-explanatory but are a quick summary of a pollination network's outward appearance (Dormann et al. 2017). We used ANINHADO (Guimarães and Guimarães 2006) to measure NODF (nestedness metric based on overlap and decreasing fill) (Almeida-Neto et al. 2008). ANINHADO allowed us to compare our data against a variety of null models to test for significance. Nestedness, web asymmetry (Moldenke 1975, Bascompte et al. 2003, Petanidou et al. 2008), and connectance (Dunne et al. 2002a, Dunne et al. 2002b), are indices that are extensively studied in plant-pollinator communities. We assume that pollinator visits to flowers are not random, so we chose these indices to measure structure and organization of pollinator communities that better explain how plant-pollinator linkages relate to ecosystem functions rather than pollinator and floral diversity (Bengtsson 1998).

Nestedness was first used to describe species distributions on islands (Patterson and Atmar 1986, Strona et al. 2014). Islands with fewer species had subsets of species from more species-rich islands and did not host species that were not present on the richer island (Patterson and Atmar 1986). Nestedness measures characteristics of plant-pollinator networks where most generalist species of one level interact with the most specialized species of another level (Bascompte et al. 2003, Beckett et al. 2014). Additionally, there are a group of generalists that interact with each other to form the "core" of the interaction network and provide redundancy of pollination service (Jordano et al. 2006). Nestedness is the most significant nonrandom pattern in ecological interactions (Jordano et al. 2006). There are several methods to measure nestedness and many theories on the best way to quantify it (Guimarães and Guimarães 2006, Almeida-Neto et al. 2008, Dormann et al. 2008, Galeano et al. 2009, Strona et al. 2014). NODF has become the accepted method because of its theoretical consistency (Almeida-Neto et al. 2008). To calculate NODF, ANINHADO uses a binary matrix (absence/presence data) to order rows and columns to detect subsets of data among the species (Guimarães and Guimarães 2006). Significance was estimated using 1,000 simulations of Monte Carlo procedures using a null model (Guimarães and Guimarães 2006, Bezerra et al. 2009) so the results can be used across studies with varying levels of sampling intensity (Dormann et al. 2009). A score of "0" is non-nested and "100" is perfectly nested (Dormann et al. 2017) To measure NODF, we converted our weighted data to absence/presence data, so an interaction was counted only once, even if it occurred multiple times.

Connectance is the realized proportion (linkages that occur divided by the maximum possible linkages) of possible linkages between pollinators and flowers within

a network (Dunne et al. 2002a, Jordano et al. 2006, Dormann et al. 2017). It is a measure to help determine the stability of a system and the system's ability to endure disturbance and species loss (Solé and Montoya 2001, Dunne et al. 2002a, Tucker and Rehan 2016). A connectance score of "0" means no interaction between species and a score of "1" is when all pollinators interact with all plants (Dunne et al. 2002b). Higher connectance indicates more generalist interactions (Fründ et al. 2010) and can indicate protection of pollination service through redundancy.

Asymmetry is a measurement of the level of non-reciprocal interactions (one member of the mutualism is more reliant on the exchange than the other) of generalist species interacting with specialist species within a network (Vázquez and Aizen 2004). Values of 0 – 0.5 are considered low to moderate and values of 0.5 – 1 are considered moderate to high (Bascompte et al. 2006).

## RESULTS

### VEGETATION DATA

#### *Percent flowering forb cover*

There were individual sampling period, land use, and land type effects on percent flowering forb cover (Table IV.2). Sampling periods 2 and 3 had higher percent cover than period 1 (Figure IV.4a). Native grasslands had the highest mean percent cover of flowering forbs but were the same as cropland. CRP flower cover was statistically similar to cropland but less than native grasslands (Figure IV.4b). Playas ($\bar{X}$ = 11.77%, SD = 14.87) had higher percent flowering forb cover than uplands ($\bar{X}$ = 8.26%, SD = 12.01), [F

(1, 1244) = 6.14, p = 0.014]. Flowering forbs present in the study site are listed in Table IV.3.

*Percent non-flowering forb cover*

There were interactions between sampling period and land use, and land use and land type on percent non-flowering forb cover (Table IV.4). Land use was significant each sampling period. In early season sampling (1), cropland ($\bar{X}$ = 8.26%, SD = 11.00) had the highest percent non-flowering forb cover but was similar to native grassland ($\bar{X}$ = 4.99%, SD = 9.08). CRP ($\bar{X}$ = 3.32%, SD = 5.54), [F (2, 96) = 3.87, p=0.024] had lower non-flowering forb cover than croplands but was similar to native grasslands. In mid-season sampling (2), croplands ($\bar{X}$ = 27.50%, SD = 22.24) had higher percent non-flowering forb cover than CRP ($\bar{X}$ = 15.31%, SD = 21.47) and native grasslands ($\bar{X}$ = 11.28%, SD = 14.35), [F (2, 96) = 7.56, p = 0.001]. In late season sampling (3), native grasslands ($\bar{X}$ = 40.04%, SD = 36.38) had the highest percent non-flowering forb cover but was similar to croplands ($\bar{X}$ = 26.56%, SD = 24.59). CRP ($\bar{X}$ = 18.11%, SD = 19.83), [F (2, 96) = 6.11, p = 0.003] had lower non-flowering forb cover than native grasslands but was similar to croplands (Figure IV.5a). There was an interaction of land use and land type. Land use effects were significant. Croplands ($\bar{X}$ = 20.89%, SD = 21.80) had the highest percent cover of non-flowering forbs. Native grassland cover ($\bar{X}$ =18.77%, SD = 27.61) was statistically similar to croplands and CRP ($\bar{X}$ = 12.25%, SD = 18.19), [F (2, 312) = 4.33, p = 0.014]. CRP had lower cover than croplands. Land type effects within land use were significant. Upland plant non-flowering forb cover ($\bar{X}$ = 27.57%, SD = 24.33) was higher than playas ($\bar{X}$ = 14.21%, SD = 16.63), [F (1, 97) = 13.60, p < 0.000]

in croplands. Playas ($\bar{X}$ = 18.88%, SD = 21.20) had higher cover than uplands ($\bar{X}$ = 8.26%, SD = 12.01), [F (1, 97) = 20.49, p < 0.000] in CRP (Figure IV.5b). Non-flowering forbs present in the study site are listed in Table IV.5.

*Percent grass cover*

There was a sampling period effect for percent grass cover (Table IV.6). Sampling periods 3 and 2 had higher grass cover than period 1 (Figure IV.6a). There was an interaction of land use and land type. Land use effects were significant. CRP ($\bar{X}$ = 40.64%, SD = 30.41) and native grasslands ($\bar{X}$ = 37.50%, SD = 25.02) had a higher percent grass cover than croplands ($\bar{X}$ = 14.27%, SD = 17.83), [F (2, 306) = 44.61, p < 0.000]. Land type effects within land use were significant. Upland plant grass cover ($\bar{X}$ = 60.36%, SD = 23.12) was higher than in playas ($\bar{X}$ =20.93%, SD = 23.25), [F (1, 97) = 105.61, p < 0.000] in CRP. Uplands ($\bar{X}$ = 45.52%, SD = 23.16) had higher cover than playas ($\bar{X}$ = 29.47%, SD = 24.42), [F (1, 97) = 18.04, p < 0.000] in native grasslands (Figure IV.6b).

When we separated grass cover into native and introduced grass species, there was also a sampling period effect and an interaction of land use and land type for percent native grass cover (Table IV.7) and percent introduced grass cover (Table IV.8). For percent native grass cover, there was a sampling period effect and an interaction of land use and land type. Sampling periods 3 and 2 had higher grass cover than period 1 (Figure IV.7a). There was an interaction of land use and land type. Land use effects were significant. Native grasslands ($\bar{X}$ = 34.95%, SD = 24.17) had the highest percent cover of native grass followed by CRP ($\bar{X}$ = 20.86%, SD = 23.11) and croplands ($\bar{X}$ = 7.83%, SD

= 12.36), [F (2, 306) = 57.02, p < 0.000]. Land type effects within land use were significant. Upland native grass cover ($\bar{X}$ = 30.32%, SD = 24.17) was higher than in playas ($\bar{X}$ = 11.41%, SD = 17.65), [F (1, 97) = 28.64, p < 0.000] in CRP. Uplands ($\bar{X}$ = 44.10%, SD = 21.92) had higher native grass cover than playas ($\bar{X}$ = 25.80%, SD = 22.98), [F (1, 97) = 30.80, p < 0.000] in native grasslands (Figure IV.7b).

Sampling periods 3 and 2 had higher introduced grass cover than period 1 (Figure IV.8a). Land use effects were significant in the land use and land type interaction. Not surprisingly, CRP ($\bar{X}$ = 19.44%, SD = 25.61) had a higher percent cover of introduced grass than cropland ($\bar{X}$ = 6.02%, SD = 12.33) and native grasslands ($\bar{X}$ = 2.32%, SD = 7.24), [F (2, 3.12) = 34.85, p < 0.000]. Land type effects within land use were significant. Upland introduced grass cover ($\bar{X}$ = 29.38%, SD = 28.27) was higher than in playas ($\bar{X}$ = 9.51%, SD = 17.98), [F (1, 97) = 31.98, p < 0.000] in CRP. Playas ($\bar{X}$ = 3.70%, SD = 9.75) had higher native grass cover than uplands ($\bar{X}$ = 0.94%, SD = 2.60), [F (1, 97) = 4.70, p < 0.000] in native grasslands (Figure IV.8b). Grasses in the study area are listed in Table IV.9.

*Percent bare soil*

There was an interaction of land use and land type for percent bare soil (Table IV.10). Land use effects were significant in the land use and land type interaction. Native grasslands ($\bar{X}$ = 61.81%, SD = 24.24) had a higher percent bare soil cover than CRP ($\bar{X}$ = 48.30%, SD = 29.98) and croplands ($\bar{X}$ = 47.25%, SD = 33.22), [F (2, 312) = 8.56, p < 0.000]. Land type effects within land use were significant. Playas ($\bar{X}$ = 53.53%, SD = 34.27) in croplands had higher bare soil cover than uplands ($\bar{X}$ = 40.96%, SD = 31.21), [F

(1, 97) = 6.10, p = 0.015. In CRP, playas ($\bar{X}$ = 61.70%, SD = 31.84) had higher percent bare soil cover than uplands ($\bar{X}$ = 34.90%, SD = 20.86), [F (1, 97) = 36.51, p < 0.000] (Figure IV.9).

*Percent duff*

There were sampling period, land use, and land type effects for duff cover (Table IV.11). Period 1 had higher duff cover than periods 2 and 3 (Figure IV.10a). Cropland had the highest duff cover, but was similar to CRP. Native grasslands had the lowest percent duff cover (Figure IV.10b). Uplands ($\bar{X}$ = 34.27%, SD = 24.46) had higher percent duff cover than playas ($\bar{X}$ = 21.80% SD = 23.73), [F (1, 297) = 33.54, p < 0.000].

*Percent embedded litter*

There were land use and land type effects for embedded litter (Table IV.12). CRP had a higher percent of embedded litter than native grasslands and cropland, which were similar (Figure III.11). Uplands ($\bar{X}$ = 5.96%, SD = 10.44) had higher embedded litter cover than playas ($\bar{X}$ = 3.13%, SD = 12.42), [F (1, 297) = 5.60, p = 0.019].

*Percent woody litter*

There was an interaction between land use and land type on percent woody litter cover (Table IV.13). Croplands ($\bar{X}$ = 7.65%, SD = 14.71) had a higher percent woody litter cover than CRP ($\bar{X}$ = 0.95%, SD = 2.22) and native grasslands ($\bar{X}$ = 0.59%, SD = 1.20), [F (2, 312) = 26.48, p < 0.000]. Land type effects within land use were significant. Playas ($\bar{X}$ = 12.15%, SD = 18.40) in croplands had higher woody litter cover than uplands ($\bar{X}$=3.16%, SD = 7.54), [F (1, 97) = 18.87, p < 0.000. In CRP, playas ($\bar{X}$ = 1.61%, SD =

2.82) had a higher percent woody litter cover than uplands ($\bar{X}$ = 0.30%, SD = 1.06), [F (1, 97) = 13.93, p < 0.000]. Native grassland uplands ($\bar{X}$ = 0.91%, SD = 1.44) had a higher percent woody litter cover than uplands ($\bar{X}$ = 0.27%, SD = 0.79), [F (1, 97) = 8.87, p = 0.004] (Figure IV.12).

*Percent canopy gap*

There was a sampling period, land use, and land type effect on canopy gap (Table III.14). Canopy gap was highest in period 1 and least in period 3 (Figure IV.13a). Croplands had the highest canopy gap and native grassland and CRP were lowest (Figure IV.13b). Playas ($\bar{X}$ = 48.74%, SD = 36.64) had higher percent canopy gap than uplands ($\bar{X}$ = 32.58%, SD = 28.15), [F (1, 297) = 27.37 p < 0.000].

*Vegetation Height*

There was a sampling period effect and an interaction between land use and land type on vegetation height (Table IV.15). Vegetation height increased with each sampling period (Figure IV.14a). Land use was significant in the interaction. Croplands ($\bar{X}$ = 23.56%, SD = 26.55) had a higher mean vegetation height than CRP ($\bar{X}$ = 17.18%, SD = 14.23) and native grasslands ($\bar{X}$ = 11.89%, SD = 13.44), [F (2, 312) = 10.98, p < 0.000]. Land type effects within land use were significant. Uplands ($\bar{X}$ = 32.87%, SD = 31.83) in croplands had a higher mean vegetation height than playas ($\bar{X}$ = 14.25%, SD = 15.28), [F (1, 97) = 18.22, p < 0.000. CRP uplands ($\bar{X}$ = 19.92%, SD = 14.39) had a higher mean vegetation height than playas ($\bar{X}$ = 14.43%, SD = 13.65), [F (1, 97) = 18.22, p = 0.035]. Native grassland uplands ($\bar{X}$ = 15.38%, SD = 15.16 had a higher mean vegetation height than playas ($\bar{X}$ = 8.39%, SD = 10.48), [F (1, 97) = 11.79, p = 0.001] (Figure IV.14b).

*Vegetation Height Variance*

There was a land type effect on vegetation height variance (Table IV.16). Uplands ($\bar{X}$ = 1,164.10, SD = 5287) had higher vegetation height variance than playas ($\bar{X}$ = 156.4, SD = 203.8), [F (1, 297) = 6.00, p = 0.015].

PATH ANALYSIS

September data for abundance and species richness trap data comparing cropland and CRP and native grassland and CRP produced the best model by AIC selection based on fit indices of $\chi^2$, (CFI), (RMSEA), and (SRMR) (Table IV.17). There is debate over the best fit index to determine the model that best represents the data (Hooper et al. 2008), and if fit indices should be used at all (Shipley 2016). Therefore, many statisticians suggest using multiple tests (Suhr 2008). Early and mid-season models (May and July) met the thresholds for best fit with SRMR, and total season models (May, July and September combined) met the threshold for SMR and CFI. Late season models (September), however, met the thresholds for all of the absolute fit indices ($\chi^2$, CFI, RMSEA, and SRMR). The model with the most superior fit for all September analyses was model 42, the direct and indirect effects of percent duff cover, percent grass cover, and land use on pollinator abundance and richness (Tables IV. 18 and 19). In these models, percent grass and duff cover mediate the effects of land use on pollinator abundance and richness rather than land use affecting abundance and richness directly.

Path diagrams for model 42 illustrate the relationships between the land use and vegetation characteristics on pollinator abundance and richness (Figures IV.15, 16, 17 and 18). A line with a single arrow means a direct relationship and a line with a double

arrow indicates correlation or covariance (Suhr 2008). In these models, all path relationships are direct except for CRP ↔ percent grass cover, cropland ↔ pollinator species richness, cropland ↔ pollinator abundance, native grassland ↔ pollinator abundance, and native grassland ↔ pollinator species richness. These paths are linked by an unknown causal relationship (Shipley 2016). Values at the intersection of paths on the path diagram (indicated by ▪ ) represent variation that is not explained by factors in the path model.

The combined direct effects of land use and vegetation characteristics and the indirect effects of vegetation characteristics within the land use determine the total effect of land use on pollinators (Figures IV.15, 16, 17, and 18). A direct effect of land use on pollinator abundance was illustrated by path (a1) (-0.089) (Figure IV.15) and is negative and small. The indirect effects of percent grass cover within each land use were represented by path (b1) and the direct effect of percent grass cover on abundance by path (b2) (-0.000042). The indirect effects of land use from percent duff cover were represented by path (c1) and the direct effect of percent duff cover on abundance by path (c2). These values combined are the indirect effects of percent grass cover and percent duff cover of land use (0.042) and are small.

When we compared effects of CRP and cropland on pollinator abundance in late season, the total effect of CRP on potential pollinator abundance was small and negative (-0.047) and cropland on pollinator abundance was medium and positive (0.205) (Table IV.20a). When CRP and native grassland were compared, the direct effects of CRP on pollinator abundance were negative and medium (-0.242), indirect effects were negative and small (-0.011), and total effects were negative and medium (-0.252). Native grassland

direct effects were negative and small (-0.153), indirect effects were positive and small (0.052), and total effects were negative and small (-0.101). The direct effects of percent grass cover on potential pollinator abundance were positive and very small (0.003) and direct effects of duff cover on pollinator abundance were positive and small (0.172) (Table IV.20b, Figure IV.16).

When CRP and cropland effects on pollinator richness were compared, CRP had a negative, medium direct effect on pollinator richness (-0.207) and cropland had a positive, small effect (0.191). The indirect effect of grass and duff cover was very small and positive for CRP (0.038) and very small and negative for cropland (-0.019). The total effects of cropland were small and positive (0.171), and small and negative (-0.169) for CRP (Table IV.20c, Figure IV.17). When we compared CRP to native grasslands, CRP had a negative and medium direct effect on potential pollinator richness (-0.398) and native grasslands had a negative and small direct effect on pollinator richness (-0.191). The indirect effects of grass and duff cover were very small and positive for CRP (0.057) and very small and positive for native grasslands (0.019). The total effects of CRP on richness were negative and medium (-0.341) and negative and small for native grasslands (-0.172) (Table IV.20d, Figure IV.18). As outlined by Suhr (2008), we then evaluated each pathway in each model for significance (Figures IV.15, 16, 17, and 18, Table IV.21).

*Partial Redundancy Analysis*

We constructed a biplot for a partial redundancy analysis with trap data from all sampling periods combined (Figure IV.19). Axis 1 expressed land type (playa or uplands)

and axis two expressed land use (cropland [AG], CRP, and native grasslands [RNG]). Land type, land use, and vegetation characteristics explained 18.5 % of the variation in the pollinator community. Of this variability, 14.36% was explained by land type, and 1.97% was explained by land use. Land use and land type associations with pollinators were not strong, but land type had a stronger effect. Both were significant ($p = 0.001$). CRP and cropland were not strongly associated with any vegetation characteristics or pollinators. Native grasslands were weakly associated with Melittidae and percent canopy gap. Playas were weakly associated with Formicidae, but were strongly positively correlated with embedded litter cover. Formicidae was also weakly positively correlated with percent grass cover. Most vegetation characteristics and pollinators were positively correlated. Percent soil cover, vegetation height variation, flower cover, non-flowering forb cover, woody litter cover, Andrenidae, Apidae, Halictidae, Chalcidae, sphecid wasps and other hymenopterans were all positively correlated. These pollinators and vegetation characteristics were negatively correlated with percent canopy gap and percent embedded litter. Melittidae, Colletidae, and Megachilidae were positively correlated with each other. Formicidae, Bombyliidae, Coleoptera, Vespidae, Lepidoptera, Syrphidae, percent grass cover, and sampling period are also positively correlated with each other and negatively correlated with the previously mentioned group (Andrenidae, Apidae, Halictidae, Chalcidae, sphecid wasps, and other hymenopterans).

*Bipartite Graphs*

We constructed bipartite graphs illustrating the plant and floral visitor interaction networks for cropland with total potential pollinators (Figure IV.20), croplands with bees (Figure IV.21), CRP with total pollinators (Figure IV.22), CRP with bees (Figure IV.23),

native grasslands with total pollinators (Figure IV.24) and grasslands with bees (Figure IV.25). The top rectangles represent flowers visited by insects, and the lower bars represent the invertebrate floral visitor. The thickness of the bars indicates the number of linkages in which the plant or floral visitor has participated - the thicker the bar, the more linkages, or a greater number of visits. Thickness of the bars/lines connecting plants to pollinators is also an indication of number of visits. We calculated basic descriptions of the networks outward appearance to enhance the bipartite graphs (Table IV.22, 23) (Dormann et al. 2017). These basic descriptors included the number of invertebrate and plant species, the number of plant families within each land use network, Shannon diversity for each land use network, and the average number of visits in which each plant or pollinator was involved (links per species). These metrics quantify what is displayed in each graph.

We used several additional ecological indices to describe patterns in the interaction networks of each land use (Table IV.22, 23) in a method similar to Tucker and Rehan (2016). These indices included nestedness measured by NODF, connectance, and web asymmetry. NODF was the only index calculated for significance. We used ecological indices to characterize the plant-pollinator interaction networks for each land use. However, these indices were not used to compare values between land uses. NODF was significant for all land uses except the network with bees in CRP (Table IV. 22, 23) and indicated low nestedness. Connectance was low for all land use networks. Web asymmetry for cropland and native grassland networks with total pollinators was moderate. CRP web asymmetry was low with total pollinators, and for all land use networks with bees. Asymmetry values were negative when there were more pollinators

in each interaction network than plants. There were more plants in the CRP and native grassland networks with bees.

## DISCUSSION

### *Vegetation characteristics of land use and effects on pollinator communities*

#### *Croplands*

Agricultural simplification of the landscape has resulted in the decline of many pollinators populations (Kevan 1999, Cane and Tepedino 2001, Goulson 2003, Potts et al. 2010, Kennedy et al. 2013). Pollinators, specifically wild bees, need rich and abundant floral resources (Potts et al. 2003a, Vaughan and Black 2008, Black et al. 2014, Woodcock et al. 2014) and nesting sites (Steffan - Dewenter and Schiele 2008, Black et al. 2014) to complete their life history. Although some agricultural lands lack floral resources for pollinators, this is not always the case (Kim et al. 2006). The primary limiting factor in most agricultural landscapes for many species of wild bees is nesting sites (Kim et al. 2006, Williams et al. 2010).

We hypothesized that croplands would have the least abundant, species richness, and diversity of pollinators of the land uses because of lower diversity of floral resources (O'Connell et al. 2012). Additionally, cultivation associated with agricultural practices results in frequent SHP soil disturbance (Smith and Haukos 2002) which could damage nesting sites of bees. Data from the years we sampled, however, did not support our hypothesis. For both trap and net samples, cropland upland and playa sites exhibited the highest abundance, richness, and diversity of total pollinators, dipterans, coleopterans and lepidopterans compared to native grassland and CRP upland and playa sites during most

sampling periods (Chapter III). These cropland metrics were similar to but often higher than native grasslands that we hypothesized would be the most abundant, rich, and diverse in pollinators. High floral cover in cropland playas likely influenced this. Although actual mean percent floral cover was lower, cropland sites were statistically similar to native grassland sites. High floral density (Vrdoljak et al. 2016) diversity (Potts et al. 2003b, Fründ et al. 2010) and abundance (Nayak et al. 2015) are correlated with high pollinator diversity, especially if the flowers are annuals (Potts et al. 2003b).

Of the nine cropland playas we sampled, seven (77%) were unplowed and protected from cultivation by fence or an unmanaged buffer strip. The percentage of unplowed playas is an unusually high representation for the SHP. For example, O'Connell et al. (2012) sampled 174 cropland playas, and 71 (41%) of those playas were unplowed. Smith and Haukos (2002) found that cropland playas had higher floral diversity than native grassland sites and were dominated by annuals and a higher percentage of exotics; however, they only sampled playas that had not been plowed. O'Connell et al. (2012) found that uncultivated cropland playas had greater wetland plant cover than what was observed in grassland playas. Cultivated playas had reduced plant cover when compared to uncultivated playas. However, cultivated playas had 3% more annuals than those that were unplowed (O'Connell et al. 2012). The interaction network and net data for croplands indicated that playa and upland annuals (*Polygonum pensylvanicum*, *Helianthus annuus*, *Symphyotrichum subulatum*, *Coreopsis tinctoria*, *Helianthus ciliaris*) and an upland exotic (*Convolvulus arvensis*) dominated insect visits.

The cropland study sites also had vegetation characteristics were favorable for nesting habitat including the highest percentage of canopy gap, woody litter, and duff

cover and highest mean vegetation height in uplands compared to CRP and native grassland. Although canopy gap indicated lack of vegetation, it potentially provided solitary bees access to soil with sun exposure where they could excavate tunnels for nests (Vaughan and Black 2008). Woody litter provided nesting sites for bees that burrow in wood and pithy stems (Vaughan and Black 2008). At plowed sites however, turnover of organic materials from cultivation may have made it undesirable as nesting material. Similarly, undisturbed duff cover is important for *Bombus* spp. queens (Black et al. 2014) and although croplands had the highest duff cover, not all of it will be undisturbed. Croplands had higher mean vegetation height because of the unmanaged buffer between the playa and the crop. Higher vegetation height can indicate more complex plant architecture and higher foliage height diversity, which was associated with higher insect diversity in some studies (Murdoch et al. 1972, Kruess and Tscharntke 2002a).

Pollinator species with varying life histories obviously respond differently to disturbance (Williams et al. 2010). Cultivated cropland generally provides marginal habitat for pollinators because of disturbance from cultivation, and many ground nesting solitary bees are sensitive to tillage (Williams et al. 2010). Some genera and species of bees, however, adapt well to disturbance, and in some landscapes, agricultural land exhibits greater abundance and richness of bees (Winfree et al. 2007). Mogren et al. (2016), however, found that agricultural intensification in the Northern Great Plains has resulted in a bee community dominated by low richness, primarily generalist species such as *Melissodes* spp. and halictids *Agapostemon* spp. and *Lasioglossum* spp. Less highly managed areas such as forage crops and aquatic habitats did not result in increased bee diversity compared to croplands which lead them to conclude that these aspects of the

landscape are also degraded (Mogren et al. 2016). Our results were similar in the SHP. *Melissodes* spp., *Agapostemon* spp. and *Lasioglossum* spp. constituted over half of bees collected (Chapter II). We did not make conclusions regarding the habitat condition of the landscapes adjacent to cropland. However, native grasslands were grazed and degraded from drought, which likely explained why cropland was often higher in pollinator abundance, richness and diversity than native grasslands. Although we did not measure floral density, cropland playas and the immediate uplands may have had higher densities of floral resources which has demonstrated to be beneficial for anthophiles (Vrdolijak et al. 2016).

Disturbance adapted pollinator species may not be the only contributing factor to high pollinator abundance, richness, and diversity in cropland. Smith and Haukos (2002) showed that plant communities in uncultivated cropland playas had similar plant richness to those of native grasslands. Additionally, the unmanaged area around most cropland playas served as an area of minimal disturbance that provided refuge for some bee species that are not adapted to disturbance. Buffer strips around playas could be more beneficial to pollinators and hydrological function of playas if native flowers (Isaacs et al. 2009, Cole et al. 2015) and native grasses are incorporated into the design rather than introduced grasses which reduce inundation, and thus function, of playas (O'Connell et al. 2012) .

*CRP*

CRP wetland and upland sites had the lowest pollinator abundance, richness, and diversity of the three land uses (Chapter III). CRP is lowest likely because this land use

had few nesting and foraging resources for pollinators, primarily wild bees. O'Connell et al. (2012) determined that CRP had twice the vegetation biomass of cropland and native grassland. Our data supported this as CRP had the highest embedded litter among land uses, similar duff cover to croplands, and the lowest amount of bare soil. CRP uplands also had the highest percentage of grass cover of all land uses, and the highest percentage of introduced grass species. There was approximately 30% cover of native grasses in CRP, however, this was not unexpected. Some native grasses such as *B. gracilis* and *B. curtipendula* were included in the initital plantings and persist at some sites. Although duff can provide nesting material for some bee species, dense embedded litter likely prevented access to soil for most solitary bees (Vaughan and Black 2008). Introduced grasses in playa catchments inhibited inundation of CRP playas, altering playa hydrology (Tsai et al. 2007) and ultimately the wetland plant community (O'Connell et al. 2012). As such, native grasses are recommended for playa buffer strips in this region (Skagen et al. 2008).

Early CRP contracts in the Texas High Plains consisted mostly of non-native grasses (Berthelsen et al. 1989), and most of these planting remain in the landscape where CRP contracts were extended. Species included in these mixes were various combinations of weeping lovegrass (*Eragrostis curvula*), Old World bluestem (*Bothriochloa ischaemum*), Kleingrass (*Panicum coloratum*), blue grama (*Bouteloua gracilis*), and sideoats grama (*Bouteloua curtipendula*) (Berthelsen et al. 1989). No flowering forbs were originally included. CRP had lower cover of flowering forbs than cropland and native grassland, which reduced abundance of flowers on which pollinators could forage. Flowering forbs that were present on each site either were from the playa

wetland, remnants from the previous land use, or colonized. Low flowering forb cover in CRP reduced foraging resources for pollinators as demonstrated by net data. Our data supported lack of foraging and nesting resources for pollinators in CRP in the SHP, especially wild bees.

*Native grasslands*

Grasslands can offer relatively undisturbed habitat for pollinators with appropriate management practices (Kevan 1999). When compared to species-rich areas such as the Mediterranean and the deserts of North America, the grasslands of the SHP have a moderate diversity of wild bee populations, especially in the more arid environments with xeric vegetation (Michener 2007).

In the SHP, the native vegetation around grassland playas protected the wetland from sediment runoff, but did not inhibit inundation and encouraged germination of a higher percentage of perennial plant species than croplands, but similar to CRP (O'Connell et al. 2012). Perennial flowering forbs are important for most species of native pollinators because they provide a consistent source of high-energy forage (Corbet et al. 1995, Delaplane 2000). Wetland and upland plant species cover are similar in native grassland sites (O'Connell et al. 2012). Because the presence of upland and wetland plants generally indicated greater forb composition than CRP or cropland sites, there is greater likelihood that there will be blooming flowers present throughout the season upon which pollinators can forage. Based on these data, we hypothesized that native grassland would have the highest abundance, species richness and diversity of pollinators among the land uses.

Native grasslands had the highest percentage of flowering forb cover over the total season and the highest percentage of native grasses. They also had the highest percentage of bare soil. These characteristics should have been ideal for foraging and nesting of pollinators (Black et al. 2011, Gilgert and Vaughan 2011). Cropland, however, had higher pollinator abundance, richness and diversity than native grasslands, or native grasslands had lower means that were statistically similar to cropland sites.

Cattle grazed all native grassland sites in this study. Intensively managed grasslands generally provide poor nest and forage resources for pollinators (Cole et al. 2015). Plant litter largely disappears under heavy grazing (Johnson et al. 1996), and this is reflected in the low percentage of duff cover we found. Additionally, native grassland uplands had the lowest mean vegetation height of uplands compared to other land uses and were statistically similar to playas in other land uses. Reduced vegetation height can also be an indication of intense grazing. Taller vegetation creates more architectural and foliage height diversity in a habitat (Murdoch et al. 1972, Woodcock et al. 2009, Black et al. 2011), resulting in more feeding niches (Kruess and Tscharntke 2002a) that support a higher diversity of insects (Kruess and Tscharntke 2002a, 2002b). Intense grazing not only reduces abundance and height of flowering forbs, but it can result in damage to the reproductive structures in plants that reduce or impedes pollination (Vázquez and Simberloff 2003).

Although bare soil is ideal for ground-nesting bees (Gilgert and Vaughan 2011, Black et al. 2014), the resulting compaction and erosion resulting from cattle activity can be detrimental to some species (Cane 1991). A high amount of soil exposure also indicates a potential lack of forage. It is also possible that native grassland sites did not

have higher richness or diversity than cropland because extended drought conditions (Chapter III) impaired grasslands from recovering from grazing pressure. The Ecological Site Description for this area of the Southern High Plains described that encroachment of or dominance of broom snakeweed (*Gutierrezia sarothrae*) and bare soil cover of >30% indicates heavy, continuous grazing (Natural Resource Conservation Service 2017). Many of the native grassland sites in our study met these criteria. Vegetation characteristics attributable to intense grazing can also be a result of extended drought, and it is likely that both contributed to native grassland conditions during the study. Moreover, mean vegetation height can vary according to the plant composition of the site. Tall vegetation in cropland may be a result of a disturbed, weedier edge and may be taller than native grasslands even in ungrazed conditions.

Grazing, however, is not always detrimental to pollinator and plant populations. Well- managed grazing systems can increase floral resources and enhance pollinator diversity (Wilkerson et al. 2013, Vanbergen et al. 2014). In some systems, especially those that evolved with large herbivores (Debano 2006, Vulliamy et al. 2006), lack of or elimination of grazing can decrease pollinator diversity (Wilkerson et al. 2013). Grazing disturbance increases heterogeneity in the landscape and supports increased plant and pollinator diversity (Wilkerson et al. 2013). Additionally, the effects of grazing do not affect all pollinators equally. Changes in pollinator populations are not always a result of increased floral diversity, but a shift in flower composition and change in the surface soil of the grassland that can change nest suitability for some species (Vulliamy et al. 2006). The shortgrass prairie evolved with large grazing mammals (Smith 2003). However, the effects of grazing cattle on pollinators should be studied in the SHP.

*Playas*

Playas had higher flowering forb cover than uplands, demonstrating that playas are an essential source of forage for pollinators in the SHP. Their importance was especially true in late season when foraging shifted from uplands to playas (Chapter III). In CRP, playas may be the primary source of pollinator forage in sites dominated by upland grasses. Although playas can provide forage resources, they likely do not provide nesting sites. Approximately 70% of wild bees nest in the ground (Black et al. 2011), and most species cannot survive flooded conditions (Michener 2007). If pollinators utilized playas for nesting sites, it would be stem or wood nesters as they will cross a water barrier to access nesting sites (Michener 2007). Starý and Tkalcú (1998), O'Neill and O'Neill (2010), and Heneberg et al. (2017) documented bees using plant stems in wetland settings, however, there is no research on use of dry wetland basins. Research on site fidelity (Potts and Willmer 1997, Steffan - Dewenter and Schiele 2004, Dorchin et al. 2013, Ogilvie and Thomson 2016) and soil texture (Potts and Willmer 1997) suggest bees would not nest in dry playa basins.

*Influence of land use and vegetation characteristics on pollinator abundance and richness*

Path analysis showed that vegetation data from late season (September) was the only sampling period where the data provided good models and satisfied the selected absolute fit indices. For 2013 and 2014, the sampling seasons started dry with few precipitation events (Chapter III) and vegetation was in poor condition. By September, limited rain events in 2013 and extensive rain events in 2014 allowed for rapid

germination and vegetation growth. There were not strong influences on pollinator abundance or richness that could be attributed to specific vegetation structure characteristics or land use independently. We expected that floral cover and bare soil or woody litter would have a strong influence on pollinator abundance and richness because these vegetation characteristics address basic foraging and nesting requirements (Cane 1991, Potts et al. 2003b, Fründ et al. 2010). The best model, however, showed that land use mediated by grass and duff cover had the most influence on pollinator abundance and richness. This suggests that pollinator abundance and richness under drought conditions was limited more by nesting site availability for ground nesters rather than foraging resources.

Grass cover could influence pollinator abundance in a few ways. High, dense grass cover reduces access to soil that would limit solitary bee's ability to excavate burrows (Black et al. 2011, Gilgert and Vaughan 2011). It can also be an indicator of low flowering forb cover (Kimoto et al. 2012b). Conversely, low grass cover can be a result of loss of biomass from grazing (Fleischner 1994) or drought. Duff cover can benefit pollinators because it provides material to build and line nests, however, if it is too dense, it can impede access to soil (Vaughan and Black 2008).

Total effects in path analysis reflect results of the univariate analysis for pollinator abundance and richness (Chapter III). CRP had a negative effect on pollinator abundance and richness when compared with cropland. As noted earlier, the likely explanation for percent grass cover being a negative indirect contributing factor is the large percentage of introduced grasses in CRP uplands and their high biomass (O'Connell et al. 2012). This may have reduced the availability of nesting sites by limiting access to the soil. The

negative indirect effect of grass cover in croplands is not clear. Duff cover had positive indirect effects on CRP and cropland, likely for its value for nesting (Vaughan and Black 2008).

When we compared CRP to native grassland, results were also similar to univariate analysis (Chapter III). The indirect effects of grass and duff cover, however, were different from CRP and cropland. For CRP and native grassland, grass cover had a positive indirect effect. For CRP, this does not support our hypothesis that the dense, non-native grasses would have a negative effect on pollinator abundance and richness. Most native grassland sites were experiencing degradation from drought and grazing as suggested by high bare soil cover and low duff. The positive indirect effects of grass for both land uses could be because sites with higher grass cover also had vegetation in better condition. The negative indirect effect of duff cover is likely due to it impeding access to nesting sites or an indicator of degraded vegetation from grazing (Johnson et al. 1996).

The models suggest that even though grass and duff cover contribute to pollinator richness and abundance, the direct effects of land use alone are much larger than indirect effects of vegetation characteristics. Additionally, the only significant paths within the models were some of the effects of land use on vegetation characteristics. These path coefficient values for grass and duff cover were supported by univariate analyses (Chapter III). The small values of direct, indirect and total effects and lack of insignificant pathways indicated that a few individual impacts rather than the model as a whole had a more profound effect on pollinator abundance and richness. Factors that were not included in the model such as weather, parasites, disease (Roulston and Goodell

2011) and adjacent land use may be more responsible for influencing pollinator abundance and richness.

*Variation in SHP pollinator community - Partial redundancy analysis*

From April 2013 through September 2014, the SHP was in various stages of drought (Chapter II). Vegetation was sparse or dead during the early sampling periods of both years and had only marginally improved during by mid-season. Because of drought conditions, study playas had been dry for several years prior to sampling. Therefore, several vegetation characteristics were difficult to differentiate between playas and uplands. Partial redundancy analysis (pRDA) for total season indicated that land use, land type and vegetation characteristics explained a small percentage of the variation in the pollinator community, and drought conditions were likely part of the unexplained variation.

The sample size from traps was large (> 70,000 specimens) and was collected over a broad geographic range, representing a diverse array of life histories. Species with varying life histories and functional traits respond differently to landscape characteristics (Williams et al. 2010, Forrest et al. 2015) that may not be easily captured at this scale. Additionally, pollinators respond differently to varying climatic conditions such as wind, temperature, and precipitation (Brittain et al. 2013).

Direct gradient analysis (pRDA) showed that overall, most pollinators and vegetation characteristics were more strongly associated with uplands than playas. Although playas had higher floral cover and were important late in the season, it is likely they did not provide nesting opportunities and for most bees and were used primarily for

foraging. Research has not determined the extent that ground nesting bees will use dry wetland basins for nesting, but studies on site fidelity (Potts and Willmer 1997, Dorchin et al. 2013, Ogilvie and Thomson 2016) and soil type preference (Steffan - Dewenter and Schiele 2004) suggest it is unlikely. Grass cover was not positively correlated with any insect group except Formicidae (ants), and that association was weak. Grass cover was negatively correlated with Megachilidae, a family of bees with many species that nest in woody, pithy, stems rather than in the soil (Michener 2007). Negative correlation between grass cover and stem nesters is likely because many sites with a high percentage of grass did not have a shrub or subshrub component that would have provided habitat for these bees.

We hypothesized that open canopy space would allow access to for bees to excavate nests in the soil. However, it was negatively correlated with most pollinator groups except Melittidae, Colletidae, and Megachilidae, albeit weakly. Bombyllidae, Syrphidae, Coleoptera, Vespidae, and Lepidoptera were not positively correlated with any specific vegetation structure, but they were correlated with land use. Land use fits with the behavior of many coleopterans and dipterans in that many species are generalist pollinators (Kevan and Baker 1983) and may not have specific habitat requirements. Partial redundancy analysis showed that land use, land type, and vegetation characteristics explained only a small portion of variation in the pollinator community, and supports conclusions from path analyses.

*Pollinator foraging and influence of playa wetlands*

Topology and structure of plant-pollinator interaction networks are becoming recognized as key in understanding diversity, community response to disturbance (Olesen et al. 2007, Ballantyne et al. 2015), and the evolution of mutualisms (Jordano 1987). One of the most valuable aspects of considering plant-pollinator interaction networks in this study is it allows us to include flowering forbs in the discussion of pollinator diversity. Pollination mutualisms receive threats to either flowers or pollinators (Kearns et al. 1998). It is important to understand how organisms interact within mutualisms and how these interactions should be considered in conservation management (Tylianakis et al. 2010).

In most plant-pollinator interaction networks, there are more species of pollinators than plant species (Dicks et al. 2002), and this is true for all interaction networks in the SHP except bee networks in CRP and native grasslands (Table IV.22, 23). Native grasslands had the most plant species and families within both networks. CRP had fewer pollinator visitors than either cropland or native grassland in total pollinator and bee networks. Although we did not measure floral density within each land use, wetlands, especially in protected cropland sites, had a higher concentration of floral resources. This suggests that to restore pollinator communities to maximum richness and abundance, we should establish more species of flowers in greater abundance and densities. Establishing a more abundant source of floral resources is possible with CRP because these sites will be protected from continuous grazing. Additionally, there will be opportunities for mid-contract management to enhance flowering forb abundance and persistence.

All land use networks had low nestedness (measured by NODF). Nestedness indicates the robustness of an interaction network (Bosch et al. 2009). This structure

protects against pollinator species loss and the effects of habitat loss (Fortuna and Bascompte 2006) because there is a core of generalist plant and pollinators with which specialists interact. A high level of nestedness allows rarer species to persist because asymmetric interactions provide potential redundancy in pollination service that protects pollination mutualisms from disturbance (Bascompte et al. 2003). Networks that are more nested have a more consistent group of generalist species interacting with the rarer or more specialized species. All land uses had low nestedness because over half of the pollinators in each network (cropland 65%, CRP 64%, and native grassland 59%) were connected to only one flower. The core of generalists was small which indicates that the network was potentially not as resilient to species loss because of lack of redundancy of pollination service. The degree of specialization determines the resilience or fragility of a network (Steffan-Dewenter et al. 2005). The less generalized a network, the more vulnerable it is to disturbance and species extinction (Steffan-Dewenter et al. 2005).

The degree of generalism in a network is measured by connectance. Connectance generally decreases as the sample size (Martinez 1992, Kearns et al. 1998) and species richness increases (Petanidou and Potts 2006). All land use networks in our study had low connectance suggesting that the plant-pollination network across the SHP is potentially unstable and prone to disruption of function from species loss (Dunne et al. 2002b). When we measured asymmetry, an aspect of nestedness, total pollinator cropland and native grassland networks were moderate, and the total pollinator CRP network and all bee land use networks were low. Asymmetry was low in these networks because they had fewer specialist and generalist species interacting. Subsequently, total pollinator CRP and all bee land use networks had more generalist pollinators visiting generalist flowers

than total pollinator cropland and native grassland networks. Each land use, however, had a mean of fewer than two linkages within the network (Table IV.22, 23), which suggests that there are not many polylectic pollinators (Murray et al. 2009) in all of the land use networks.

Bipartite graphs also allowed us to determine the most frequently visited flowering forbs within each land use. One of our objectives was to determine the importance of obligate wetland or facultative wetland plants to pollinators. In cropland, *Polygonum pensylvanicum* was an important food source for pollinators, and with *Helianthus annuus,* had the most visits from pollinators. Wetland-residing plants hosting multiple pollinator visits in cropland also included *Symphyotrichum subulatum, Coreopsis tinctoria,* and *Sagittaria longiloba*. In CRP wetland sites, *Malvella leprosa, Polygonum pensylvanicum,* and *Lythrum californicum* were important wetland plants in pollinator diets. Pollinators had more visits to uplands plants in native grassland sites than cropland or CRP because more upland plant species were present in the network. However, wetland species *Sagittaria longiloba*, *Polygonum pensylvanicum*, and *Polygonum ramosissimum,* all wetland plants, were frequently visited by pollinators. Obligate wetland, facultative wetland and facultative flowering forbs are a major component of pollinator forage in the SHP. Forage plants visited by pollinators in the SHP are listed in Table IV.3, and the most important for consideration in seeding mixes are included in the conclusion.

As research on plant-pollinator interaction networks progresses, so does the need to develop more consistent and thorough sampling standards. In a study to examine the completeness of sampling in a desert interaction network, (Chacoff et al. 2012)

determined that even under intensive sampling methods, they detected less than 60% of interactions. To detect as many interactions as possible, sampling methods should include diurnal and nocturnal collection, extend over multiple years, and take place over entire flowering periods (Petanidou et al. 2008). When Bosch et al. (2009) included data from analysis of pollen collected from pollen loads on bees, four new interacting functional groups of pollinators and flowers were revealed in the network that were not detected with field samples alone. In a long-term study, species classified as specialists in the first year were classified as generalists after four years of data collection (Petanidou et al. 2008). Minckley et al. (2000) and Dicks et al. (2002) increased sampling intensity by collecting three times a day to capture a range of varying flight times. In one of the most intensive sampling efforts, pollinators were collected every third half hour starting at sunrise and continued after sunset (Petanidou and Potts 2006). We sampled for two years from April – September, every two weeks, which is consistent with many of longer-term studies that range from one to four years (Alarcon et al. 2008, Petanidou et al. 2008, Carstensen et al. 2016). A six-month sampling period allowed us to capture the progression of emerging pollinators and flowers through the end of the growing season. We collected every two weeks to ensure that we did not miss any seasonal flight or bloom times. If we had sampled multiple times during the day, however, we may have detected interactions not captured in our 1.5 hour/day sampling window and reclassified monolectic pollinators as oligolectic or polylectic. We did not capture several genera of apids that were found in our blue vane traps such as *Anthophora* spp., *Centris* spp., *Svastra* spp., and *Eucera* spp. (Chapter II), and these may have been captured if we

sampled over several time windows in the day. Additionally, we may have been able to detect pollinators we did capture on more species of flowers.

With bipartite graphs, we detected ten monolectic and reciprocal interactions where a specialist interacts with a specialist (cropland 2, CRP 3, and native grasslands 5). These reciprocal mutualisms, interactions where the pollinator and plant are equally reliant upon each other, are not common in plant-pollinator networks (Armbruster 2006, Jordano et al. 2006, Willmer 2011f). The presence of multiple monolectic species may indicate we have missed some interactions.

## CAVEATS, CONCLUSIONS, AND RECOMMENDATIONS

Our study demonstrated that CRP lands had lower pollinator abundance, richness, and diversity than cropland and native grassland. We also demonstrated that cropland had higher or statistically similar pollinator abundance, richness and diversity than native grassland. Although the biological differences between land uses were small, our results were consistent and suggest the vegetation characteristics of the land uses are the primary reason for the difference in pollinator communities.

Several factors could have influenced our results. Cropland playas and adjacent uplands were the most protected sampling sites of all land uses that were included in the study. All but two were isolated from cultivation with a fence, by a defacto buffer strip, or both. This likely biased our results because O'Connell et al. (2012) found that 59% of randomly selected playas embedded in cropland did not have buffers and were planted in crops. In our study, only 22% of cropland playas were plowed and without buffer strips (2 of 9), and one site was no-till with reduced disturbance from cultivation. We expected

native grassland sites to have higher abundance, species richness, and diversity of pollinators than cropland and CRP sites. However, croplands were higher or statistically similar to native grasslands in pollinator abundance and richness. Floral cover of cropland wetlands and uplands was less than, but statistically similar to native grasslands. Playas had higher floral cover than uplands, and the higher floral cover in wetlands was a strong influence in the overall floral cover of each land use. The likely explanation is the cropland sites were protected from grazing which allowed for higher quality and constant floral resource on which pollinators could forage. Additionally, the active agricultural operations surrounding the cropland playas provided enough disturbance to maintain a constant supply of annual floral resources.

Another potential confounding factor was in 2013, large populations of sugarcane aphids (*Melanaphis sacchari*) were detected in several counties in the southeast United States, including Texas (Texas A&M AgriLife Extension 2017a). In 2014, these pests were documented as present in two counties in our study, Briscoe and Floyd (Texas A&M AgriLife Extension 2017a) (Figure IV.26). The significance of these insects is they feed on *Sorghum* spp. and produce large amounts of honeydew (Texas A&M AgriLife Extension 2017a), which has been demonstrated to be used by a broad range of native bees as a sugar resource, especially in the absence of flowers (Meiners et al. 2017). *Sorghum* spp. were present in five counties in our study. In 2013 and 2014, we found Johnsongrass (*Sorghum halepense*) in Hockley, Lubbock and Carson cropland sites and sudangrass (*Sorghum bicolor* ssp. *drummondii*) in a field adjacent to our Bailey native grassland site. In 2013, producers planted grain sorghum (*Sorghum bicolor* ssp. *bicolor*) in the uplands and playa of the Bailey cropland site. In 2014, grain sorghum was planted

in the playa and uplands of the Gray cropland site, and was present in surrounding fields at the Swisher and Lubbock cropland sites. Although we did not scout for the presence of these pests, their presence in the region could have influenced the amount of bees flying in proximity of the blue vane traps if infested sorghum fields were close to our sampling sites.

All native grassland sites were actively grazed in this study. Although grazing is not always a detriment to floral communities, the extended drought degraded native grasslands (Chapter II), and grazing under these conditions affected the quality of the floral component. CRP had consistently less abundant, species-rich, and diverse pollinator communities. The high cover of dense, non-native grasses inhibited playa inundation, reduced availability of nesting sites for most solitary bees, and was likely the reason for lower pollinator abundance, richness, and diversity. When designing a CRP seed mix, managers should consider the following recommendations to improve pollinator habitat in the SHP and for CRP contracts in this region:

1. Fencing and protecting cropland playas with a buffer can create refugia for pollinators while still allowing cultivation of uplands. Sedimentation of playas indirectly affects pollinators by reducing the native forb cover in the wetland (Smith and Haukos 2002). Creating upland buffers strips with native grasses such as *B. gracilis* and *B. dactyloides* can reduce sedimentation in the playa. These upland buffer strips should include a flowering forb component that includes native flowers currently and/or historically found in native grasslands (Table IV.24). Haukos et al. (2016) determined that an adequate width of upland buffer strips should be 40-60 m, with >80% vegetation cover. In addition to providing forage for pollinators and re-establishing a more natural

hydroperiod, these buffer strips can remove 50-87% of sediments, nutrients, and metals from runoff (Haukos et al. 2016). Sediment removal from playas can be cost prohibitive (Luo et al. 1997), but effective (Beas et al. 2013). Restoration of a natural hydroperiod (Smith and Haukos 2002, O'Connell et al. 2012) and reliance on existing seedbanks for annuals, but reseeding of perennials (Beas et al. 2013) should be the priority for wetland flowering forbs.

2. Land use mediated by percent grass and duff cover was the primary influencing factors in pollinator abundance and richness in the SHP. Therefore, the grass component of CRP seed mixes should include only native grasses that historically occurred in the landscape such as *B. gracilis* and *B. dactyloides* (Coffey and Stevens 2012). Replacing introduced, exotic tall grass species with native shortgrass prairie grasses will reduce the density of vegetation cover in the CRP uplands, as indicated by less cover and duff in native grasslands, and provide more nesting sites for ground nesting solitary wild bees (Black et al. 2011, Gilgert and Vaughan 2011). Less grass cover will also reduce competition for establishment of flowering forbs.

3. Plants recommended for inclusion in buffer and CRP seeding mixes are native upland plants listed in Table IV.24. We based these recommendations on insect visitation the plant-pollinator networks of each land use. When preparing a seed mix, it is important to consider budget, blooming period to cover early to late season, and a mix of annuals and perennials. Most flowers in Asteraceae are important to pollinators, however, the seed mix should focus on including perennial Asteraceae rather than being overly reliant on easy to establish annuals that may already be present in the seedbank. Perennials are a persistent source of high-energy forage for pollinators (Corbet et al. 1995, Corbet 2000)

that were not abundant in our study area. At sampling sites with a protected buffer between the upland and playa, there was an adequate seed bank of frequently visited facultative and facultative upland annuals and a perennial (Haukos and Smith 1993, Smith and Haukos 2002, USDA and NRCS 2017) such as *Helianthus annuus, Helianthus ciliaris* and *Coreopsis tinctoria.* Although *Helianthus ciliaris* has been determined by the Xerces Society and the Lady Bird Johnson Wilflower Center to be of special value to native bees, this flower is considered a noxious weed in six states (USDA and NRCS 2017). It does not have this legal classification in Texas, however, its weedy and invasive tendencies suggest it should not be included in a seedmix and reliance on seedbank is adequate.

Menz et al. (2011) recommended identifying the species of flowering forbs utilized by the most pollinator species over the flight season when designing a seed mix. Based on the intensity of pollinator visits illustrated in our bipartite graphs, we recommend that a selection of *Grindelia papposa, Grindelia squarrosa, Sphaeralcea coccinea, Verbesina encelioides, Heterotheca stenophylla, Machaeranthera pinnatifida, Engelmannia persistenia, Hymenopappus flavescens, Ratibida columnifera* and *Ratibida tagetes* be included in CRP seedmixes for this region of Texas. Incorporating these flowers in the mix will preserve the most frequent plant-pollinator connections and ensure a reliable and established foraging source for local bees. Because of the degraded condition of the native grassland during the study, many flowers were not abundant, and species that would likely be attractive to pollinators were not found in transects, or only sporadically in isolated patches adjacent to sampling sites. These included *Asclepias latifolia, Asclepias verticillata, Centaurea americana, Dalea jamesii, Engelmannia*

*peristenia, Liatris punctata, Heterotheca villosa, Machaeranthera tanacetifolia, Cirsium ochrocentrum, Vernonia marginata,* and *Chaetopappa ericoides.* Even though our bipartite graphs did not document these flowers as frequently fed upon, the lack of visitation could be because of limited sampling during the day, or because of low representation within transects. Including some of these flowers in the seed mix will allow us to maintain or strengthen connections that may be under-represented or may be in jeopardy of extinction due to loss of the floral resource. Other flowers listed as present in the SHP and not seen during our study, but documented in past research that are beneficial to pollinators are *Achillea millefolium, Dalea purpurea, Monarda punctata (*Holm 2017*), Amorpha canescens* (Haukos and Smith 1997, Lee-Mader et al. 2016, Holm 2017), *Sphaeralcea angustifolia, Sphaeralcea hastulata* (Haukos and Smith 1997), and *Berlandiera lyrata* (Natural Resource Conservation Service 2017). The importance of including these flowers is to re-establish plant-pollinator connections that may have been lost or strenghten those that are under-represented in our sampling efforts.

4. The Natural Resource Conservation Service recommends that at least 25% of a seeding mix should include native grasses (NRCS 2011). Based on the Ecological Site Description for this area (Natural Resource Conservation Service 2017), these grasses should be a mix of *B. gracilis* and *B. dactyloides.*

5. The Natural Resource Conservation Service recommends 15% of a seeding mix to be a shrub component (NRCS 2011). Land managers should consider *Baccharis salicina, Desmanthus illinoensis*, and *Amorpha canescens*. The Xerces Society and the Lady Bird Johnson Wilflower Center determined that *Prosopis glandulosa* (honey mesquite) is of special significance to native bees, honey bees, and provides nesting material and

structure to native bees. If honey mesquite is present within fields or in field margins, landowers should preserve them if possible. It is unlikely that this plant would be included in a seed mix as it can be poisonous to cattle and landowners often remove it from agricultural production areas (Texas A&M AgriLife Extension 2017b).

6. Although not all CRP contract holders can provide grazing for mid-contract management, this management option should be considered. Grazing can enhance floral diversity if conducted under an acceptable grazing management plan (Gilgert and Vaughan 2011). Further research is needed on the effects of grazing on CRP in the SHP to determine ideal stocking rates and density for grazing to be a viable management option.

7. We did not consider landscape scale effects or patch size in this study. Our sampling was limited to the playa and the immediate uplands. Solitary bee species differ in maximum foraging distances from their nest (Gathmann and Tscharntke 2002, Zurbuchen et al. 2010). These distances are generally determined by body length (Gathmann and Tscharntke 2002), but can vary considerably (Zurbuchen et al. 2010). The land use surrounding our sampling sites varied, especially for cropland sites. Further evaluation of our data should include determing land use at distances beyond our sampling sites based on maximum foraging distance of solitary bees of assorted body sizes. Additionally, we did not consider the size of each sampling unit. Playas varied in size and playa and upland area could have influenced the species and abundance of insects collected at each site. Blaauw and Isaacs (2014) demonstrated that larger and more species rich patches of flowers resulted in denser and more diverse populations of wild bees. When we estimate maximum foraging distance of pollinators, we should compare the size of the sampling

area, patch size of flower resources, and the percentage of land use and land types represented in each sampling site.

8. Our results indicated that cropland sites generally had higher pollinator abundance, richness and diversity. We concluded that the protected and undisturbed condition of seven of nine playas might be more hospitable to pollinators than the native grasslands with heavy grazing pressure and CRP land with high percentage on non-native tall grasses and lower floral cover than the other land uses. Source-sink dynamics however, may have influenced pollinator capture in croplands. Evaluation of land use around each sampling site and size of the sampling site may help determine if land use alone is adequate to explain differences in pollinator abundance, richness and diversity.

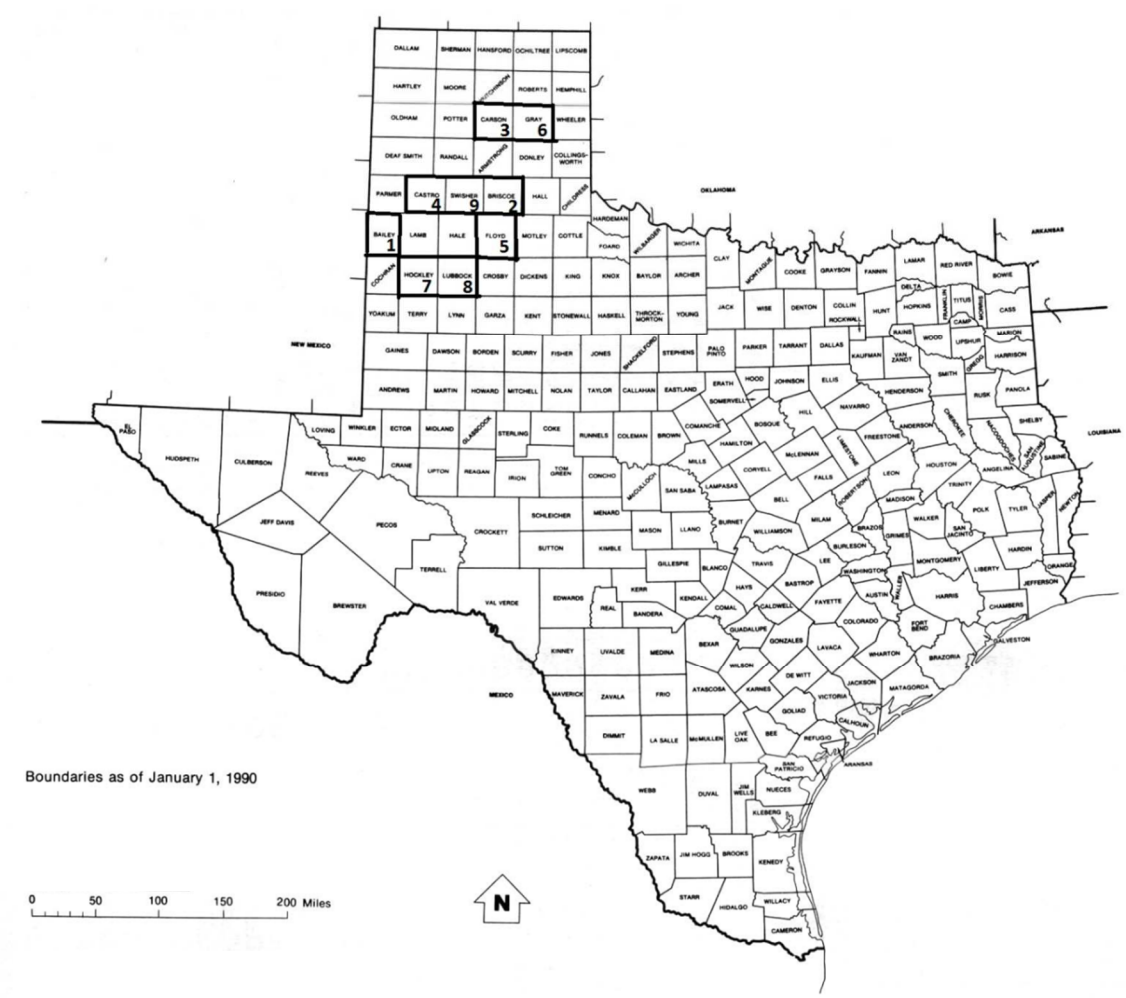



Figure IV.1. Texas High Plains Counties included in study 2013-2014. 1. Bailey 2. Briscoe 3. Carson 4. Castro 5. Floyd 6. Gray 7. Hockley 8. Lubbock 9. Swisher. Map courtesy of the University of Texas Libraries, The University of Texas at Austin.

Figure IV.2. Example of sampling site for 2013-2014 study in Texas High Plains. There was a playa and its catchment for each land use in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties. There were 3 sets of parallel transects in the playa and 3 sets in the uplands for a total of 27 sampling sites. Data from the playas and uplands were pooled separately into 2 sampling units.

Figure IV.3. Path model showing all possible direct and indirect effects of land use and vegetation characteristics on pollinator abundance and species richness in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. "LU" represents land use, either CRP and native grassland or CRP and cropland, "Flower" represents % flower cover, "Grass" represents % grass cover, "Forb" represents % non-flowering forb cover, "Soil" represents % of ground covered by bare soil, "Duff" represents % of ground covered by duff, defined as loose plant material that is not a separate layer from soil, "EL" represents % of ground covered by embedded litter, defined as a compacted layer of plant material that is separate from the soil and will cause an indention in the soil if removed, "WL" represents % of ground covered by woody vegetation material, "Canopy Gap" represents % of vegetation canopy without vegetation cover, and "Veg Ht Variation" represents the variance in vegetation height in a sampling unit.

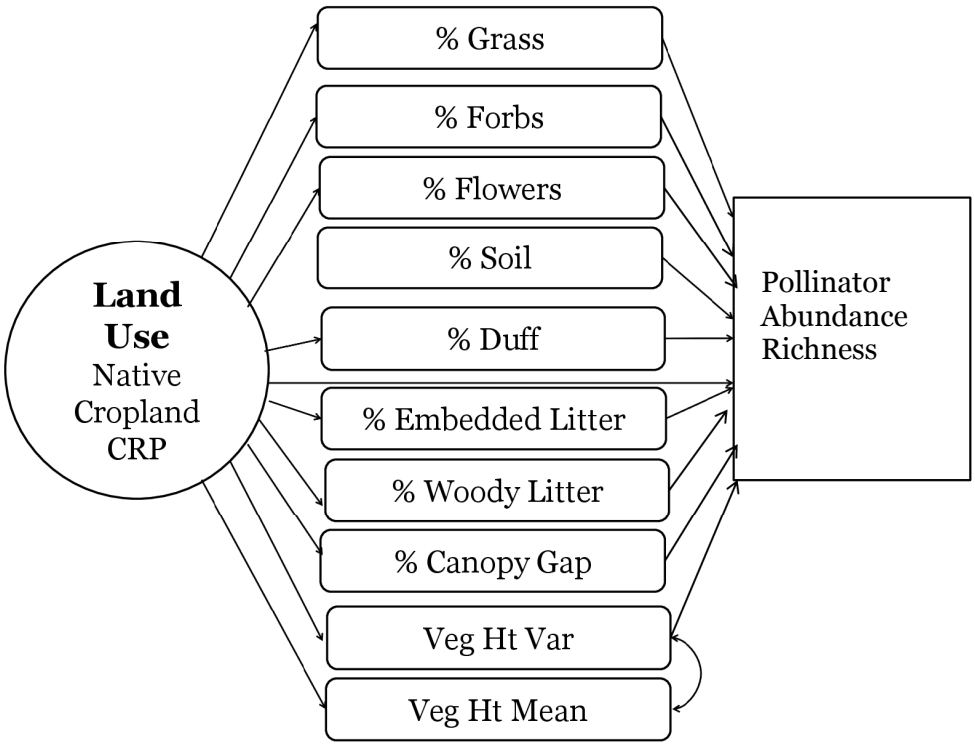


Table IV.1 Path Models predicting pollinator abundance and richness for AIC used selection. Potential models to determine the best fit for effects of land use and vegetation characteristics on pollinator abundance and species richness in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. "LU" represents land use, either CRP and native grassland or CRP and cropland, "Flower" represents % flower cover, "Grass" represents % grass cover, "Forb" represents % non-flowering forb cover, "Soil" represents % of ground covered by bare soil, "Duff" represents % of ground covered by duff, defined as loose plant material that is not a separate layer from soil, "EL" represents % of ground covered by embedded litter, defined as a compacted layer of plant material that is separate from the soil and will cause an indention in the soil if removed, "WL" represents % of ground covered by woody vegetation material, "Canopy Gap" represents % of vegetation canopy without vegetation cover, and "Veg Ht Variation" represents the variance in vegetation height in a sampling unit.

| Model # | Explanatory Variables |
|---|---|
| 1 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+Veg Ht Variance+LU |
| 2 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+Veg Ht Variance |
| 3 | LU |
| 4 | Null |
| 5 | Flower+Duff+Canopy Gap+Veg Ht Variance+LU |
| 6 | Flower+Duff+Canopy Gap+Veg Ht Variance |
| 7 | Flower+Soil+Canopy Gap+Veg Ht Variance+LU |
| 8 | Flower+Soil+Canopy Gap+Veg Ht Variance |
| 9 | Flower+EL+Canopy Gap+Veg Ht Variance+LU |
| 10 | Flower+EL+Canopy Gap+Veg Ht Variance |
| 11 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance+LU |
| 12 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance |
| 13 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU |
| 14 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance |
| 15 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU |
| 16 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance |
| 17 | Flower+Duff+LU |
| 18 | Flower+Duff |
| 19 | Flower+Duff+WL+LU |
| 20 | Flower+Duff+WL |
| 21 | Flower+Soil+LU |
| 22 | Flower+Soil |
| 23 | Flower+Soil+WL+LU |
| 24 | Flower+Soil+WL |
| 25 | Flower+Duff+Canopy Gap+LU |
| 26 | Flower+Duff+Canopy Gap |
| 27 | Flower+Soil+Canopy Gap+LU |
| 28 | Flower+Soil+Canopy Gap |
| 29 | Flower+EL+Canopy Gap+LU |
| 30 | Flower+EL+Canopy Gap |
| 31 | Grass+Duff+Canopy Gap+Veg Ht Variance |
| 32 | Grass+Soil+Canopy Gap+Veg Ht Variance+LU |
| 33 | Grass+Soil+Canopy Gap+Veg Ht Variance |
| 34 | Grass+EL+Canopy Gap+Veg Ht Variance+LU |

Table IV. Continued

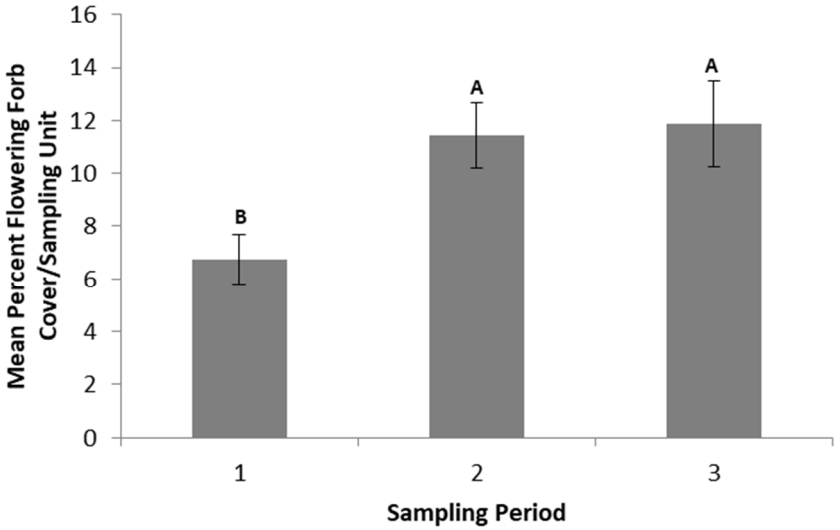
| | |
|---|---|
| 35 | Grass+EL+Canopy Gap+Veg Ht Variance |
| 36 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance+LU |
| 37 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance |
| 38 | Grass+Soil+WL+Canopy Gap+Veg Ht Variance+LU |
| 39 | Grass+Soil+WL+Canopy Gap+Veg Ht Variance |
| 42 | Grass+Duff+LU |
| 43 | Grass+Duff |
| 44 | Grass+Duff+WL+LU |
| 45 | Grass+Duff+WL |
| 46 | Grass+Soil+LU |
| 47 | Grass+Soil |
| 48 | Grass+Soil+WL+LU |
| 49 | Grass+Soil+WL |
| 50 | Grass+Duff+Canopy Gap+LU |
| 51 | Grass+Duff+Canopy Gap |
| 52 | Grass+Soil+Canopy Gap+LU |
| 53 | Grass+Soil+Canopy Gap |
| 54 | Grass+EL+Canopy Gap+LU |
| 55 | Grass+EL+Canopy Gap |

Table IV.2. ANOVA results for effects of sampling period, land use, and land type on percent flowering forb cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Flowering forb cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 5.39 | 0.005 |
| Land Use | F(2,297) = 4.10 | 0.017 |
| Land Type | F(1,297) = 6.14 | 0.014 |
| Sampling period x Land Use | F(4,297) = 0.92 | 0.455 |
| Sampling period x Land Type | F(2,297) = 0.43 | 0.650 |
| Land use x Land type | F(2,297) = 1.67 | 0.191 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.33 | 0.857 |

Figure IV.4 Effects of sampling period, land use, and land type on percent flowering forb for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent flowering forb cover – sampling period, b.) Percent flowering forb cover – land use.

a.



b.

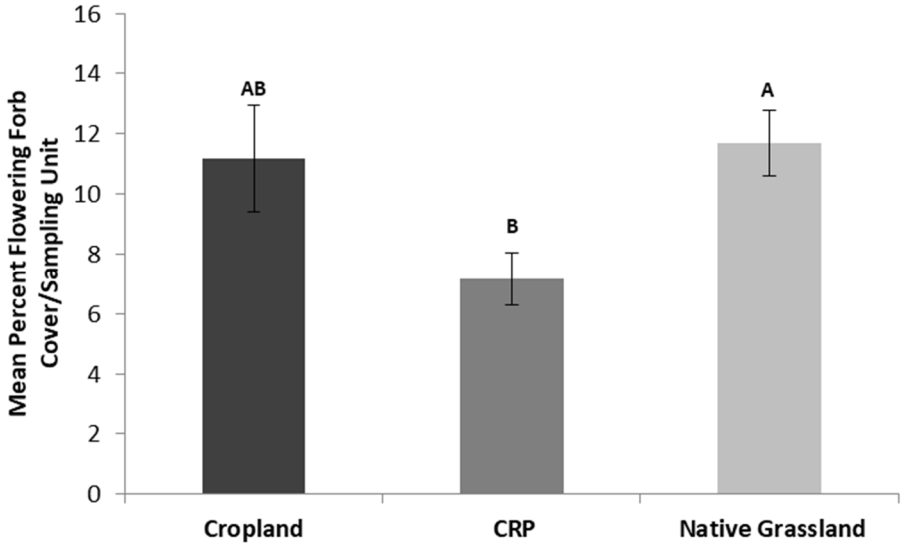

Mean Percent Flowering Forb Cover/Sampling Unit
16
14
12
10
8
6
4
2
0
AB
B
A
Cropland
CRP
Native Grassland

Table IV.3. Flowering forbs on which pollinators were captured within transects in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Symbol is the USDA designation for the plant, status is native or introduced, and land use is the land use in which it was found (AG = cropland, CRP, NG = native grassland). N/A indicates no wetland status was indicated on USDA Plant Database (USDA and NRCS 2017).

| Plant | USDA Symbol | Native Status | Family | Wetland Status | Land Use |
|---|---|---|---|---|---|
| *Amaranthus retroflexus* | AMRE | n | Amaranthaceae | FACU | crp |
| *Ambrosia grayi* | AMGR5 | n | Asteraceae | FAC | ng |
| *Amphiachyris dracunculoides* | AMDR | n | Asteraceae | N/A | ag, ng |
| *Asclepias latifolia* | ASLA4 | n | Asclepiadaceae | N/A | ng |
| *Asclepias verticillata* | ASVE | n | Asclepiadaceae | N/A | crp |
| *Bassia scoparia* | BASC5 | i | Chenopodiaceae | FACU | crp |
| *Chaetopappa* sp. | CHAET | n | Asteraceae | N/A | ng |
| *Chamaesaracha* sp. | CHAM8 | n | Solanaceae | N/A | ng |
| *Chamaesyce albomarginata* | CHAL11 | n | Euphorbiaceae | N/A | crp |
| *Chenopodium album* | CHAL7 | i,n | Chenopodiaceae | N/A | ng |
| *Chenopodium leptophyllum* | CHLE4 | n | Chenopodiaceae | N/A | ag, crp, ng |
| *Cirsium ochrocentrum* | CIOC2 | n | Asteraceae | N/A | crp, ng |
| *Cirsium* sp. | CISC | i,n | Asteraceae | N/A | ag, ng |
| *Convolvulus arvensis* | COAR | i | Convolvulaceae | N/A | ag, crp |
| *Convolvulus equitans* | COEQ | n | Convolvulaceae | FACU | crp, ng |
| *Conyza Canadensis* | COCA5 | n | Asteraceae | N/A | ag |
| *Coreopsis tinctoria* | COTI3 | n | Asteraceae | FAC | ag, crp, ng |
| *Cuscuta squamata* | CUSQ | n | Cuscutaceae | N/A | ag, ng |
| *Dalea jamesii* | DAJA | n | Fabaceae | N/A | ng |
| *Descurainia* sp. | DES | n | Brassicaceae | N/A | ag |
| *Descurainia pinnata* | DEPI | n | Brassicacea | N/A | ag |
| *Echinocactus texensis* | ECTE | n | Cactaceae | N/A | ng |
| *Engelmannia peristenia* | ENPE4 | n | Asteraceae | N/A | ng |
| *Erigeron modestus* | ERMO2 | n | Asteraceae | N/A | ag, crp, ng |
| *Erysimum repandum* | ERRE4 | i | Brassicaceae | N/A | crp, ng |
| *Euphorbia marginata* | EUMA8 | n | Euphorbiaceae | FACU | crp, ng |
| *Gossypium hirsutum* | GOHI | n | Malvaceae | UPL | ag |
| *Grindelia papposa* | GRPA8 | n | Asteraceae | UPL | ag, crp, ng |
| *Grindelia squarrosa* | GRSQ | n | Asteraceae | UPL | ag, crp, ng |
| *Gutierrezia sarrothrae* | GUSA2 | n | Asteraceae | N/A | crp, ng |
| *Helianthus annuus* | HEAN3 | n | Asteraceae | FACU | ag, crp, ng |
| *Helianthus ciliaris* | HECI | n | Asteraceae | FAC | ag, crp, ng |
| *Helianthus petiolaris* | HEPE | n | Asteraceae | N/A | ag |
| *Heterotheca stenophylla* | HEST3 | n | Asteraceae | N/A | crp |
| *Heterotheca villosa* | HEVI4 | n | Asteraceae | N/A | crp, ng |
| *Hymenopappus flavescens* | HYFL | n | Asteraceae | N/A | crp, ng |
| *Hymenoxys odorata* | HYOD | n | Asteraceae | N/A | ng |
| *Krameria lanceolate* | KRLA | n | Krameriaceae | N/A | ng |
| *Liatris punctate* | LIPU | n | Asteraceae | N/A | ng |
| *Lygodesmia juncea* | LYJU | n | Asteraceae | N/A | ng |
| *Lythrum californicum* | LYCA4 | n | Lythraceae | OBL | ag, crp |
| *Machaeranthera pinnatifida* | MAPI | n | Asteraceae | UPL | crp, ng |
| *Machaeranthera tanacetifolia* | MATA2 | n | Asteraceae | UPL | ag, crp, ng |
| *Malvella leprosa* | MALE3 | n | Malvaceae | FAC | ag, crp, ng |

Table IV.3. Continued

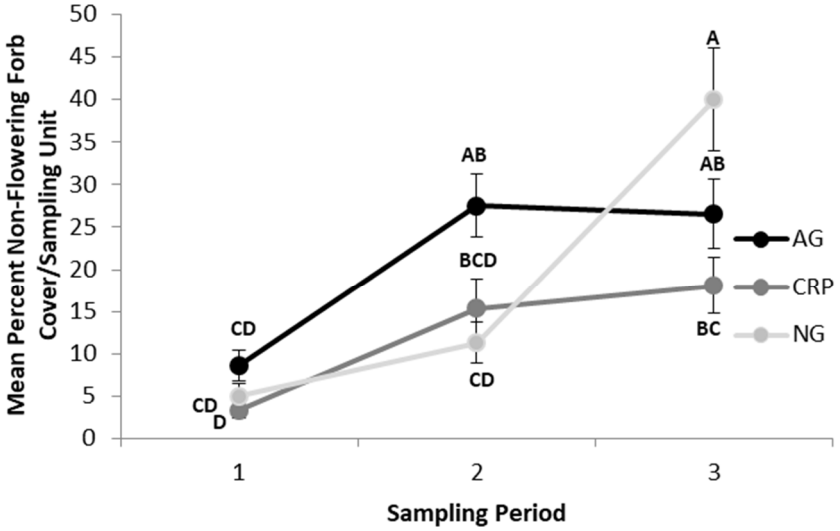
| | | | | | |
|---|---|---|---|---|---|
| *Medicago sativa* | MESA | i | Fabaceae | UPL | crp |
| *Melampodium leucanthum* | MELE2 | n | Asteraceae | N/A | ng |
| *Mimosa borealis* | MIBO2 | n | Fabaceae | N/A | ng |
| *Nothoscordum bivalve* | NOBI2 | n | Liliaceae | FACU | ng |
| *Oenothera canascens* | OECA | n | Onagraceae | FAC | ag, ng |
| *Oenothera macrocarpa* | OEMA | n | Onagraceae | N/A | ag |
| *Opuntia engelmannii* | OPEN | n | Cactaceae | N/A | ng |
| *Opuntia phaeacantha* | OPPH | n | Cactaceae | N/A | ng |
| *Phacelia congesta* | PHCO2 | n | Hydrophyllaceae | N/A | ng |
| *Phyla nodiflora* | PHNO2 | n | Verbenaceae | FAC | ag, crp, ng |
| *Physalis viscosa* | PHVI17 | n | Solanaceae | N/A | ng |
| *Polygonum amphibium* | POAM8 | n | Polygonaceae | N/A | ag, crp, ng |
| *Polygonum pensylvanicum* | POPE2 | n | Polygonaceae | FACW | ag, crp, ng |
| *Polygonum ramosissimum* | PORA3 | n | Polygonaceae | FACW | crp, ng |
| *Portulaca oleracea* | POOL | n | Portulaceae | FAC | ng |
| *Proboscidea louisianica* | PRLO | n | Pedaliaceae | FACU | ag, ng |
| *Prosopis glandulosa* | PRGL2 | n | Fabaceae | FACU | ng |
| *Psilostrophe tagetina* | PSTA | n | Asteraceae | N/A | ng |
| *Ratibida columnifera* | RACO3 | n | Asteraceae | N/A | ag, ng |
| *Ratibida tagetes* | RATA | n | Asteraceae | N/A | ag, crp, ng |
| *Rorippa sinuata* | ROSI2 | n | Brassicaceae | FACW | ag, crp, ng |
| *Sagittaria longiloba* | SALO2 | n | Alismataceae | OBL | ag, ng |
| *Solanum elaeagnifolium* | SOEL | n | Solanaceae | N/A | ag, crp, ng |
| *Solanum rostratum* | SORO | n | Solanaceae | N/A | ag, crp, ng |
| *Sphaeralcea coccinea* | SPCO | n | Malvaceae | N/A | crp, ng |
| *Symphyotrichum subulatum* | SYSU5 | n | Asteraceae | OBL | ag, crp, ng |
| *Tetraneuris scaposa* | TESC | n | Asteraceae | N/A | ng |
| *Thelesperma ambiguum* | THAM4 | n | Asteraceae | N/A | crp |
| *Thelesperma megapotamicum* | THME | n | Asteraceae | N/A | crp |
| *Tribulus terrestris* | TRTE | i | Zygophyllaceae | N/A | ag |
| *Verbesina encelioides* | VEEN | n | Asteraceae | FAC | ag, crp |
| *Vernonia marginata* | VEMA | n | Asteraceae | FAC | ng |
| *Xanthisma texanum* | XATE | n | Asteraceae | N/A | ag, crp, ng |

Table IV.4. ANOVA results for effects of sampling period, land use, and land type on percent non-flowering forb cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Non-flowering forb cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 37.97 | <0.000 |
| Land Use | F(2,297) = 6.02 | 0.003 |
| Land Type | F(1,297) = 0.17 | 0.678 |
| Sampling period x Land Use | F(4,297) = 6.92 | <0.000 |
| Sampling period x Land Type | F(2,297) = 0.16 | 0.851 |
| Land use x Land type | F(2,297) = 13.33 | <0.000 |
| Sampling period x Land Use x Land Type | F(4,297) = 1.53 | 0.192 |

Figure IV.5 Effects of sampling period, land use, and land type on percent non-flowering forb for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent non- flowering forb cover – sampling period x land use, b.) Percent non-flowering forb cover – land use x land type.

a.



b.

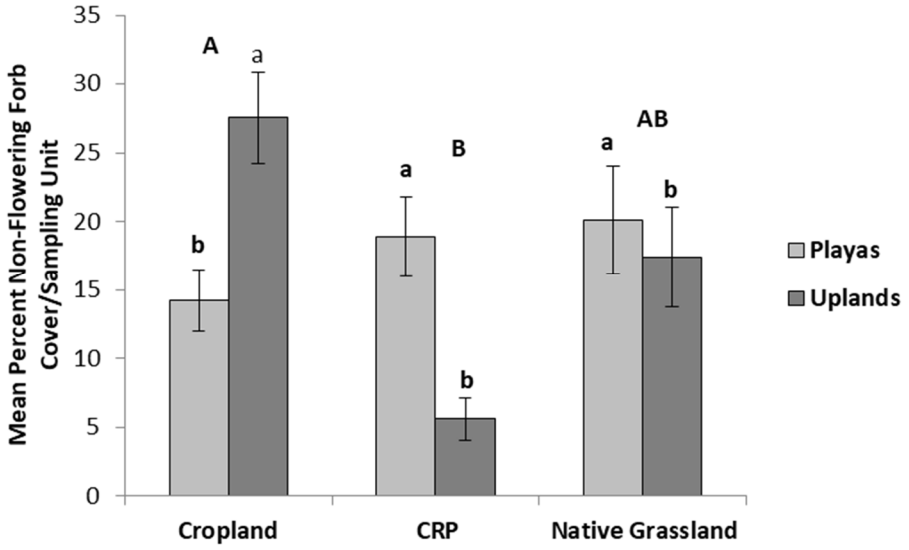

Mean Percent Non-Flowering Forb Cover/Sampling Unit
35
30
25
20
15
10
5
0
A
a
b
a
B
b
a
AB
b
Cropland
CRP
Native Grassland
Playas
Uplands

Table IV.5. Non-flowering forb species found within transects in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Symbol is the USDA designation for the plant, status is native or introduced, and land use is the land use in which it was found (AG = cropland, CRP, NG = native grassland). N/A indicates no wetland status was indicated on USDA Plant Database (USDA and NRCS 2017).

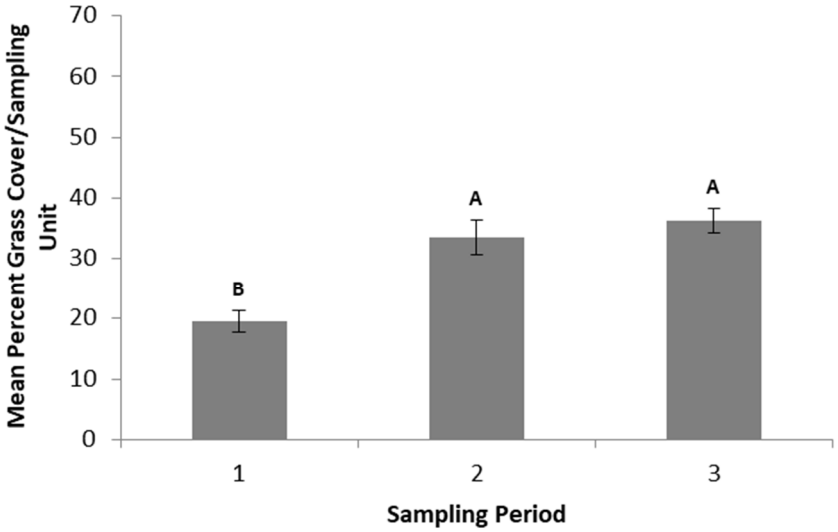
| **Plant Name** | **Symbol** | **Status** | **Land Use** |
|---|---|---|---|
| *Amaranthus albus* | AMAL | i | ag, crp, ng |
| *Amaranthus retroflexus* | AMRE | n | ag, crp, ng |
| *Ambrosia filifolia* | ARFI2 | n | crp |
| *Ambrosia grayi* | AMGR | n | ag, crp, ng |
| *Ambrosia psilostachya* | AMPS | n | ag, crp, ng |
| *Bassia scoparia* | KOSC | i | ag, crp, ng |
| *Chamaesyce albomarginata* | CHAL11 | n | ag, crp, ng |
| *Chenopodium album* | CHAL7 | n | ag, crp, ng |
| *Chenopodium leptophyllum* | CHLE4 | n,i | ag, crp, ng |
| *Croton spp.* | CROTON | n, i | ng |
| *Marsilea vesita* | MAVE2 | n | ag, ng |
| *Plantago helleri* | PLHE | n | crp, ng |
| *Rumex crispus* | RUCR | n | ag |
| *Salsola tragus* | SAIB | i | ag, crp, ng |
| *Suckleya suckleyana* | SUSU | n | ag, ng |
| *Ulmus pumila* | ULPU | i | ag |

Table IV.6. ANOVA results for effects of sampling period, land use, and land type on percent grass cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late, land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Grass cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 32.68 | <0.000 |
| Land Use | F(2,297) = 64.82 | <0.000 |
| Land Type | F(1,297) = 82.11 | <0.000 |
| Sampling period x Land Use | F(4,297) = 2.20 | 0.069 |
| Sampling period x Land Type | F(2,297) = 1.21 | 0.299 |
| Land use x Land type | F(2,297) = 29.73 | <0.000 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.453 | 0.453 |

Figure IV.6. Effects of sampling period, land use, and land type on percent grass cover for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent grass cover – sampling period, b.) Percent grass cover – land use x land type.

a.



b.

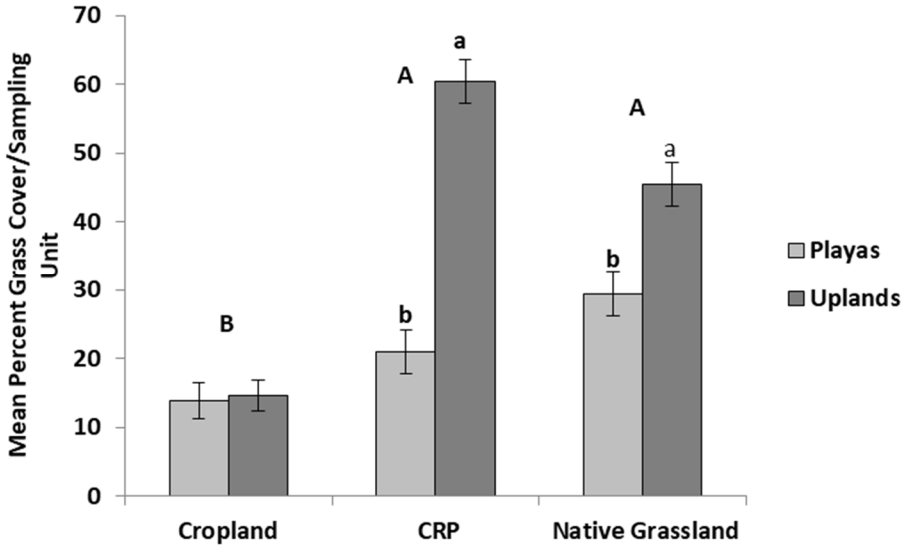

Mean Percent Grass Cover/Sampling Unit
70
60
50
40
30
20
10
0
B
b
A
a
b
A
a
Cropland
CRP
Native Grassland
Playas
Uplands

Table IV.7. ANOVA results for effects of sampling period, land use, and land type on percent native grass cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

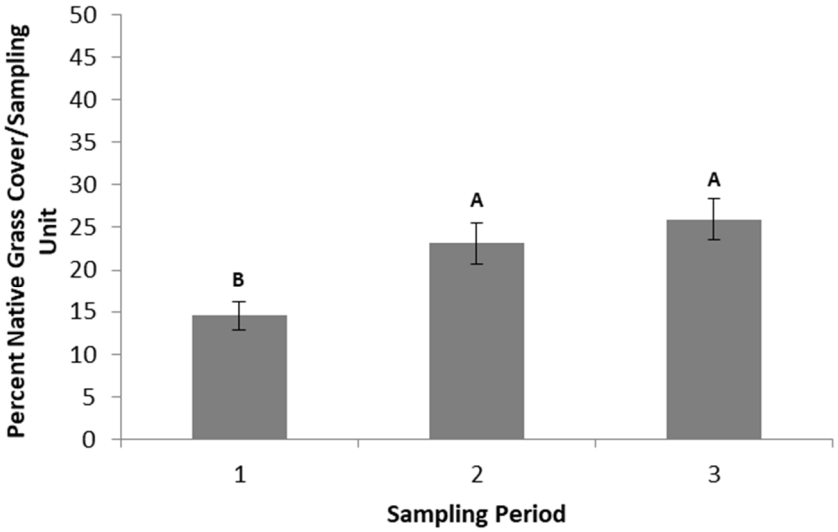
| **% Native grass cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 13.01 | <0.000 |
| Land Use | F(2,297) = 66.81 | <0.000 |
| Land Type | F(1,297) = 36.00 | <0.000 |
| Sampling period x Land Use | F(4,297) = 1.75 | 0.139 |
| Sampling period x Land Type | F(2,297) = 0.22 | 0.806 |
| Land use x Land type | F(2,297) = 13.76 | <0.000 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.41 | 0.799 |

Table IV.8. ANOVA results for effects of sampling period, land use, and land type on percent introduced grass cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Introduced grass cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 8.72 | <0.000 |
| Land Use | F(2,297) = 42.25 | <0.000 |
| Land Type | F(1,297) = 17.74 | <0.000 |
| Sampling period x Land Use | F(4,297) = 1.61 | 0.173 |
| Sampling period x Land Type | F(2,297) = 0.43 | 0.652 |
| Land use x Land type | F(2,297) = 17.97 | <0.000 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.71 | 0.586 |

Figure IV.7. Effects of sampling period, land use, and land type on percent native grass cover for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent native grass cover – sampling period, b.) Percent native grass cover – land use x land type.

a.



b.

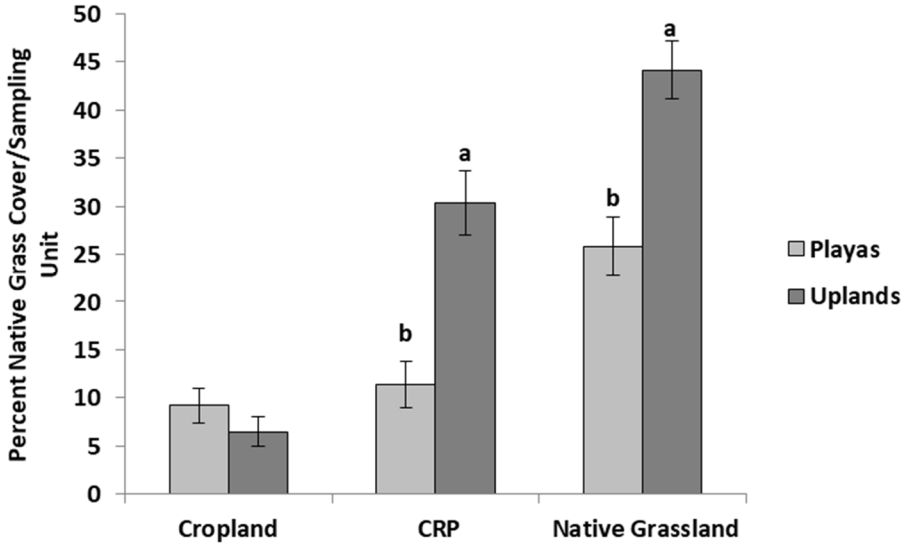
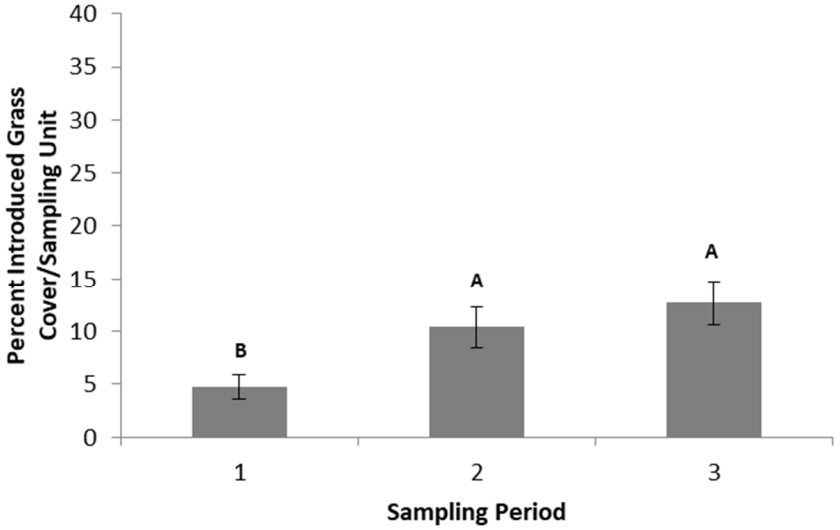

Percent Native Grass Cover/Sampling Unit
50
45
40
35
30
25
20
15
10
5
0
a
a
b
b
Cropland
CRP
Native Grassland
Playas
Uplands

Figure IV.8. Effects of sampling period, land use, and land type on percent introduced grass cover for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent introduced grass cover – sampling period, b.) Percent introduced grass cover – land use x land type.

a.



b.

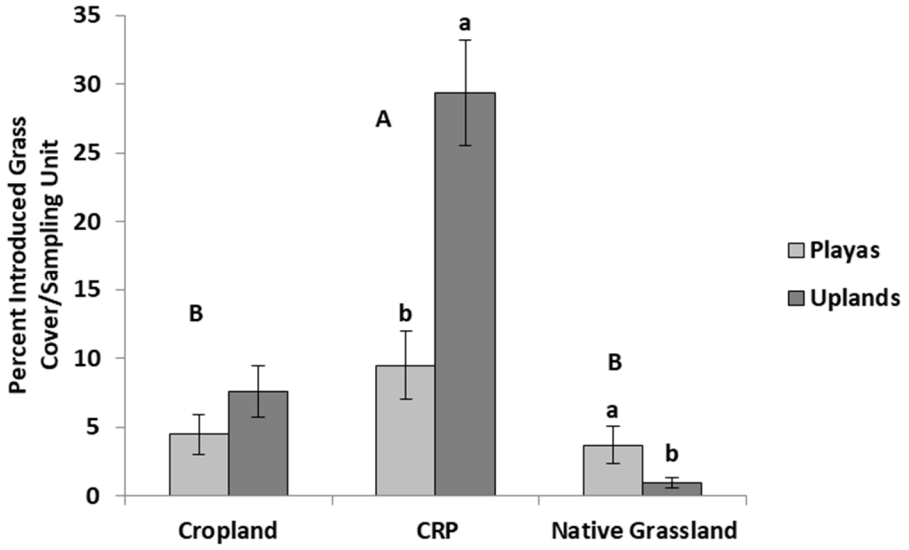

Percent Introduced Grass Cover/Sampling Unit
35
30
25
20
15
10
5
0
B
A
B
a
b
a
b
Cropland
CRP
Native Grassland
Playas
Uplands

Table IV.9. Grass or graminoid species found within transects in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Symbol is the USDA designation for the plant, status is native or introduced, and land use is the land use in which it was found (AG = cropland, CRP, NG = native grassland). N/A indicates no wetland status was indicated on USDA Plant Database (USDA and NRCS 2017).

| **Plant Name** | **Native Status** | **Land Use** |
|---|---|---|
| *Aristida purpurea* | n | crp, ng |
| *Bothriochloa ischaemum* | i | ag, crp, ng |
| *Bothriochloa laguroides* | i,n | crp |
| *Bouteloua curtipendulum* | n | crp |
| *Bouteloua dactyloides* | n | ag, crp, ng |
| *Bouteloua gracilis* | n | ag, crp, ng |
| *Bromus arvensis* | i | ag, crp, ng |
| *Bromus catharticus* | i | ag |
| *Bromus hordeaceus* | i | ng |
| *Bromus spp.* | i,n | crp |
| *Chloris verticillata* | n | ng |
| *Echinochloa colona* | i | ng |
| *Echinochlora crus-galli* | i | ag, crp, ng |
| *Eleocharis macrostachya* | n | ag, crp, ng |
| *Eragrostis spp.* | i | ag, ng |
| *Hordeum jubatum* | n | ag, crp |
| *Hordeum pusilum* | n | ag, crp, ng |
| *Leptochloa dubia* | n | crp |
| *Leptochlora fusca* | n | ag, ng |
| *Panicum capillare* | n | ag, crp ng |
| *Panicum coloratum* | i | crp |
| *Panicum obtusum* | n | ag, crp, ng |
| *Pascopyrum smithii* | n | ag, crp, ng |
| *Paspalum distichum* | n | crp, ng |
| *Phalaris caroliniana* | n | ng |
| *Schedonnardus paniculatus* | n | ag, ng |
| *Scleropogon brevifolius* | n | ng |
| *Setaria vulpiseta* | n | ng |
| *Sorghum bicolor* ssp *bicolor* | i | ag |
| *Sorghum halapense* | i | ag |
| *Sporobolus cryptandrus* | n | ag, ng |
| *Triticum* spp. | i | ag |

Table IV.10. ANOVA results for effects of sampling period, land use, and land type on percent bare soil. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Bare soil** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 1.08 | 0.341 |
| Land Use | F(2,297) = 9.13 | <0.000 |
| Land Type | F(1,297) = 20.49 | <0.000 |
| Sampling period x Land Use | F(4,297) = 0.29 | 0.887 |
| Sampling period x Land Type | F(2,297) = 0.59 | 0.556 |
| Land use x Land type | F(2,297) = 5.04 | 0.007 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.21 | 0.933 |

Figure IV.9. Effects of land use, and land type on percent bare soil for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Total season land uses and sampling periods with the same letter are not statistically different.

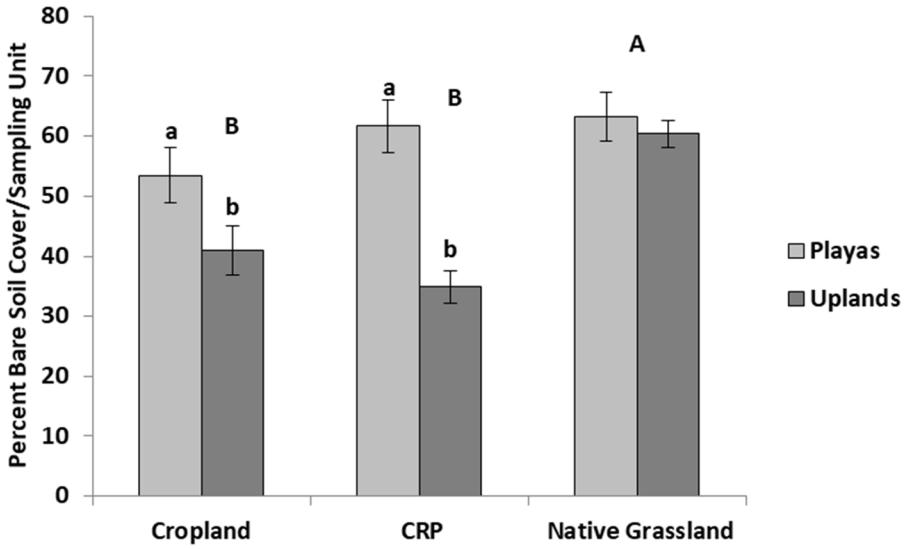
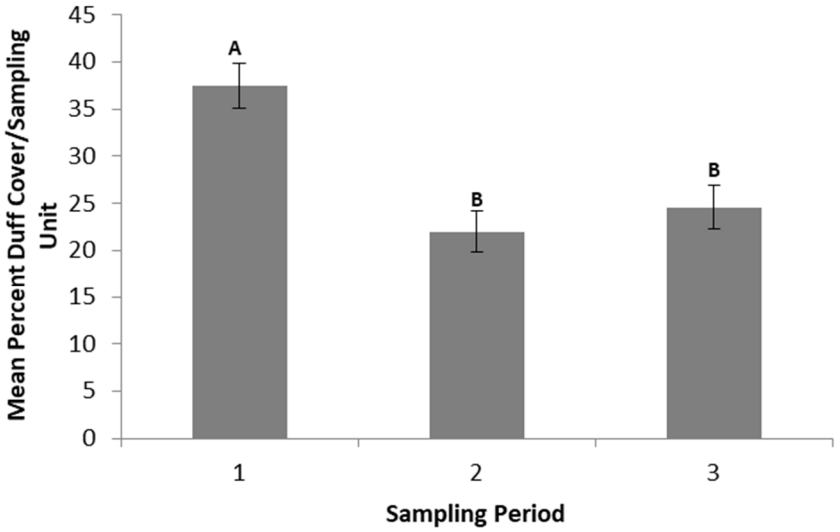


Table IV.11. ANOVA results for effects of sampling period, land use, and land type on percent duff cover. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Duff cover** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 19.89 | <0.000 |
| Land Use | F(2,297) = 22.04 | <0.000 |
| Land Type | F(1,297) = 33.54 | <0.000 |
| Sampling period x Land Use | F(4,297) = 0.13 | 0.973 |
| Sampling period x Land Type | F(2,297) = 1.05 | 0.353 |
| Land use x Land type | F(2,297) = 2.71 | 0.068 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.15 | 0.964 |

Figure IV.10. Effects of sampling period, land use, and land type on percent duff for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. a.) Percent duff cover – sampling period, b.) Percent duff – land use.

a.



b.

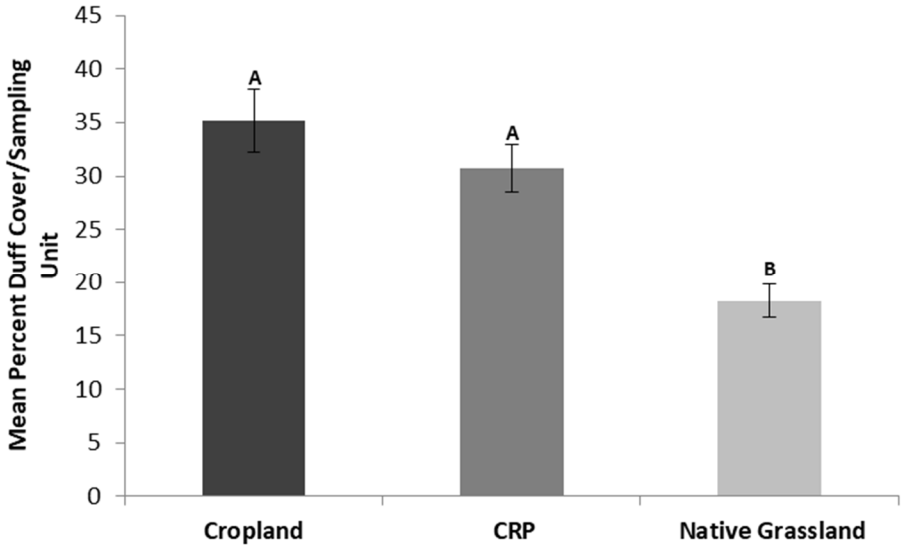

Mean Percent Duff Cover/Sampling Unit
45
40
35
30
25
20
15
10
5
0
A
A
B
Cropland
CRP
Native Grassland

Table IV.12. ANOVA results for effects of sampling period, land use, and land type on percent embedded litter. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Embedded litter** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 0.35 | 0.702 |
| Land Use | F(2,297) = 8.86 | <0.000 |
| Land Type | F(1,297) = 5.60 | 0.019 |
| Sampling period x Land Use | F(4,297) = 1.72 | 0.146 |
| Sampling period x Land Type | F(2,297) = 0.79 | 0.456 |
| Land use x Land type | F(2,297) = 0.51 | 0.598 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.32 | 0.867 |

Figure IV.11. Effects of land use, and land type on percent embedded litter for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Total season land uses and sampling periods with the same letter are not statistically different.

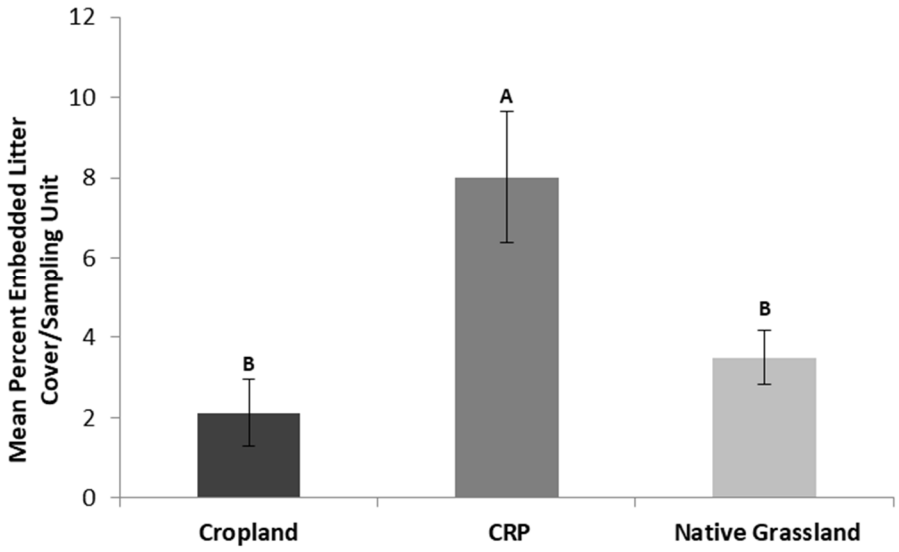


Table IV.13. ANOVA results for effects of sampling period, land use, and land type on percent woody litter. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Woody litter** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 0.58 | 0.563 |
| Land Use | F(2,297) = 29.07 | <0.000 |
| Land Type | F(1,297) = 10.60 | 0.001 |
| Sampling period x Land Use | F(4,297) = 0.68 | 0.608 |
| Sampling period x Land Type | F(2,297) = 0.63 | 0.534 |
| Land use x Land type | F(2,297) = 13.74 | <0.000 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.57 | 0.681 |

Figure IV.12. Effects of sampling period, land use, and land type on percent woody litter for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different.

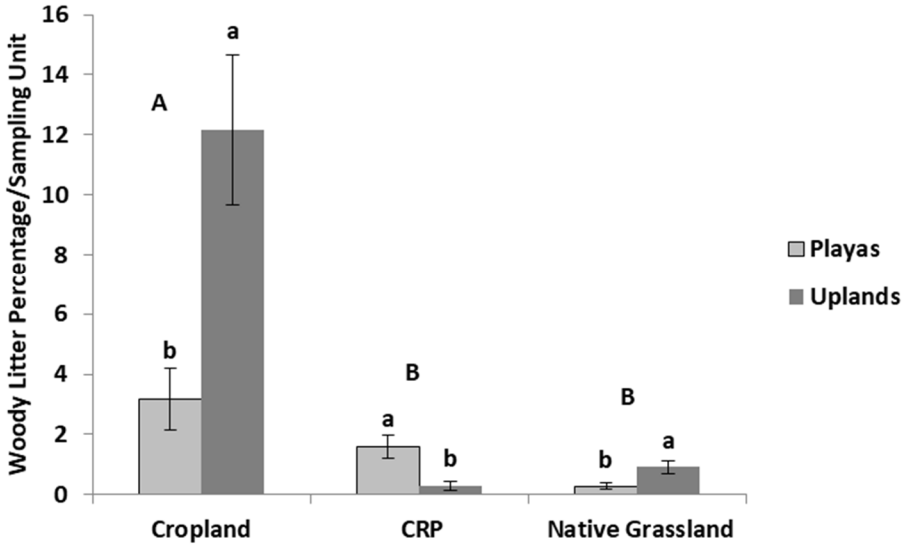
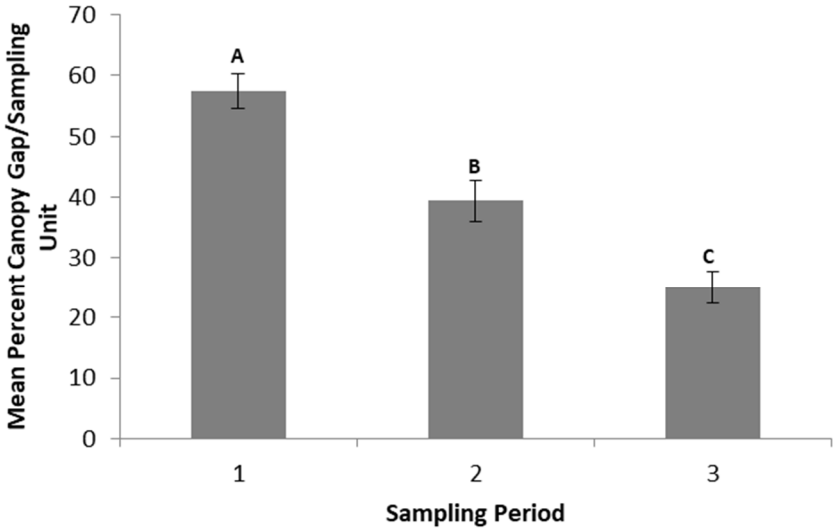


Table IV.14. ANOVA results for effects of sampling period, land use, and land type on percent canopy gap. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **% Canopy gap** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 37.51 | <0.000 |
| Land Use | F(2,297) = 7.32 | 0.001 |
| Land Type | F(1,297) = 27.37 | <0.000 |
| Sampling period x Land Use | F(4,297) = 1.94 | 0.103 |
| Sampling period x Land Type | F(2,297) = 0.10 | 0.903 |
| Land use x Land type | F(2,297) = 0.53 | 0.591 |
| Sampling period x Land Use x Land Type | F(4,297) = 1.01 | 0.402 |

Figure IV.13. Effects of sampling period, land use, and land type on percent canopy gap for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. a.) Percent canopy gap – sampling period, b.) Percent canopy gap – land use.

a.



b.

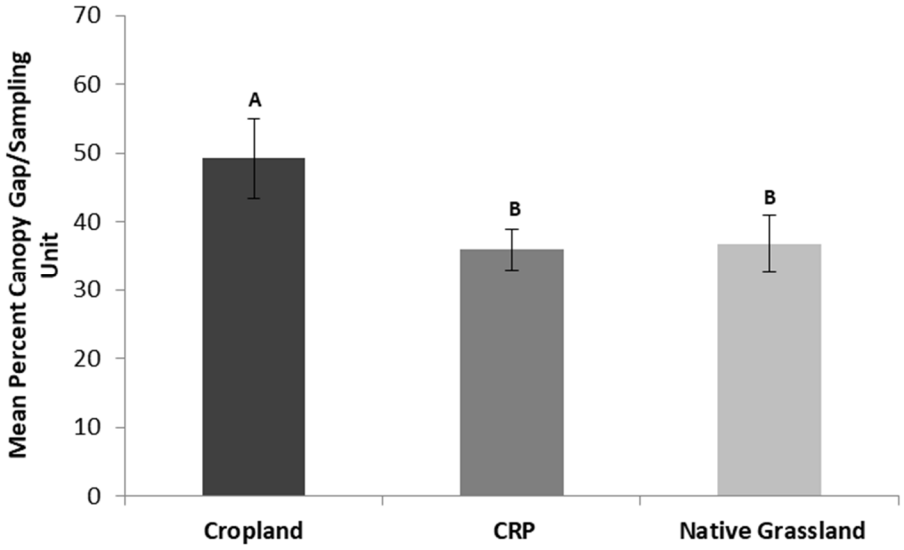
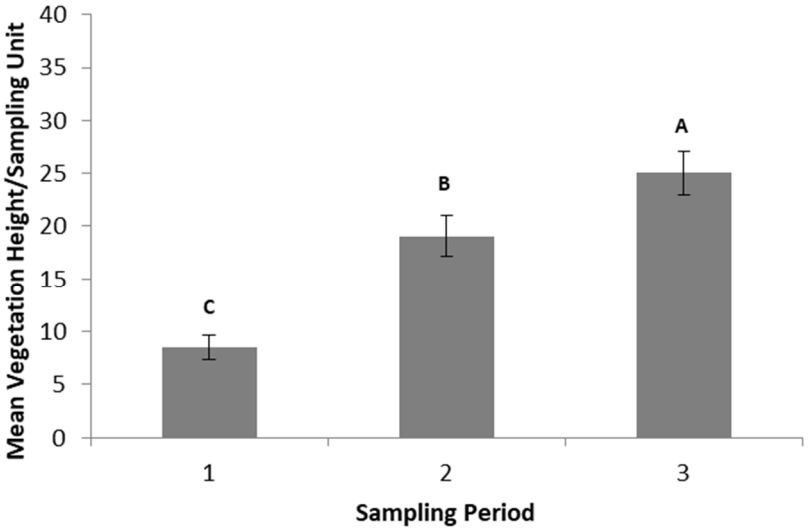

Mean Percent Canopy Gap/Sampling Unit
70
60
50
40
30
20
10
0
A
B
B
Cropland
CRP
Native Grassland

Table IV.15. ANOVA results for effects of sampling period, land use, and land type on mean vegetation height. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas in 2013-2014. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **Mean vegetation height** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 30.04 | <0.000 |
| Land Use | F(2,297) = 14.62 | <0.000 |
| Land Type | F(1,297) = 34.55 | <0.000 |
| Sampling period x Land Use | F(4,297) = 1.80 | 0.129 |
| Sampling period x Land Type | F(2,297) = 0.95 | 0.389 |
| Land use x Land type | F(2,297) = 5.53 | 0.004 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.88 | 0.476 |

Figure IV.14. Effects of sampling period, land use, and land type on mean vegetation height for playas and uplands sampled in 2013-2014. Vegetation data were collected in the Texas High Plains counties of Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher. Sampling period is early (1), mid (2), and late (3) season. Total season land uses and sampling periods with the same letter are not statistically different. Height was measured in centimeters. a.) Mean vegetation height – sampling period, b.) Mean vegetation height – land use x land type.

a.



b.

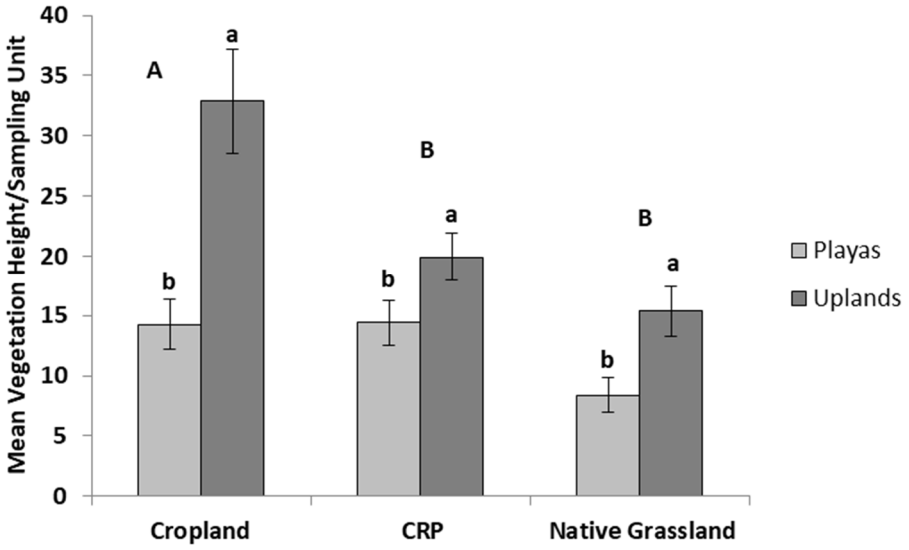

Mean Vegetation Height/Sampling Unit
40
35
30
25
20
15
10
5
0
A
a
b
B
a
b
B
a
b
Cropland
CRP
Native Grassland
Playas
Uplands

Table IV.16. ANOVA results for effects of sampling period, land use, and land type on vegetation height variance. Vegetation data were collected Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties of the High Plains of Texas. Sampling period is early, mid, and late season. Land use is cropland, Conservation Reserve Program, and native grassland. Land type is playa or upland.

| **Vegetation height variance** | **F-Value, df** | **p-value** |
|---|---|---|
| Sampling period | F(2,297) = 0.88 | 0.415 |
| Land Use | F(2,297) = 2.69 | 0.069 |
| Land Type | F(1,297) = 6.00 | 0.015 |
| Sampling period x Land Use | F(4,297) = 0.55 | 0.702 |
| Sampling period x Land Type | F(2,297) = 0.94 | 0.392 |
| Land use x Land type | F(2,297) = 2.58 | 0.077 |
| Sampling period x Land Use x Land Type | F(4,297) = 0.64 | 0.632 |

Table IV.17. Evaluation of model fit for SEM path analysis involves several statistical tests to determine significance. Several absolute fit indices (Hooper et al. 2008) were used to test the effects of vegetation and land use on pollinator abundance and species richness using data collected early season, mid-season, and late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Late season (September) had the best fit with all absolute fit indices. $\chi^2$ values should be close to zero with a probability > 0.05 (Suhr 2008). Comparative Fit Index (CFI) ranges from 0-1 with a higher value indicating better model fit (Hu and Bentler 1999, Suhr 2008). Root Mean Square Error of Approximation (RMSEA) is acceptable with a value of 0.06 or less (Hu and Bentler 1999, Suhr 2008). Standardized root mean square residual (SRMR) should be less than 0.08 (Hu and Bentler 1999).

| | **Best model** | **dAIC** | **Akaike weight** | **df** | $\chi^2$ | **p value** | **CFI** | **RMSEA** | **SRMR** |
|---|---|---|---|---|---|---|---|---|---|
| **Early Season (May)** | | | | | | | | | |
| Cropland/CRP abundance | 46 | 0.0 | 0.679 | 11 | 12.12 | <0.000 | 0.751 | 0.321 | 0.077 |
| Native grassland/CRP abundance | 46 | 0.0 | 0.679 | 11 | 12.12 | <0.000 | 0.751 | 0.321 | 0.077 |
| Cropland/CRP richness | 46 | 0.0 | 0.597 | 11 | 12.12 | <0.000 | 0.724 | 0.321 | 0.076 |
| Native grassland/CRP richness | 46 | 0.0 | 0.597 | 11 | 12.12 | <0.000 | 0.724 | 0.321 | 0.076 |
| **Mid-Season (July)** | | | | | | | | | |
| Cropland/CRP abundance | 42 | 0.0 | 0.937 | 11 | 6.332 | 0.012 | 0.898 | 0.222 | 0.050 |
| Native grassland/CRP abundance | 42 | 0.0 | 0.937 | 11 | 6.332 | 0.012 | 0.898 | 0.222 | 0.050 |
| Cropland/CRP richness | 42 | 0.0 | 0.958 | 11 | 6.332 | 0.012 | 0.897 | 0.222 | 0.051 |
| Native grassland/CRP richness | 42 | 0.0 | 0.958 | 11 | 6.332 | 0.012 | 0.897 | 0.222 | 0.051 |
| **Late Season (September)** | | | | | | | | | |
| Cropland/CRP abundance | 42 | 0.0 | 0.977 | 11 | 0.686 | 0.407 | 1.00 | 0.00 | 0.018 |
| Native grassland/CRP abundance | 42 | 0.0 | 0.977 | 11 | 0.686 | 0.407 | 1.00 | 0.00 | 0.018 |
| Cropland/CRP richness | 42 | 0.0 | 0.980 | 11 | 0.686 | 0.407 | 1.00 | 0.00 | 0.018 |
| Native grassland/CRP richness | 42 | 0.0 | 0.980 | 11 | 0.686 | 0.407 | 1.00 | 0.00 | 0.018 |
| **Total Season** | | | | | | | | | |
| Cropland/CRP abundance | 42 | 0.0 | 0.999 | 11 | 9.067 | 0.003 | 0.933 | 0.158 | 0.037 |
| Native grassland/CRP abundance | 42 | 0.0 | 0.999 | 11 | 9.067 | 0.003 | 0.933 | 0.158 | 0.037 |
| Cropland/CRP richness | 42 | 0.0 | 0.999 | 11 | 9.067 | 0.003 | 0.938 | 0.158 | 0.037 |
| Native grassland/CRP richness | 42 | 0.0 | 0.999 | 11 | 9.067 | 0.003 | 0.938 | 0.158 | 0.037 |

Table IV.18. AIC values for path models explaining pollinator abundance using September data for CRP, croplands, native grasslands, and vegetation characteristics in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. "LU" represents land use, either CRP and native grassland or CRP and cropland, "Flower" represents % flower cover, "Grass" represents % grass cover, "Forb" represents % non-flowering forb cover, "Soil" represents % of ground covered by bare soil, "Duff" represents % of ground covered by duff, defined as loose plant material that is not a separate layer from soil, "EL" represents % of ground covered by embedded litter, defined as a compacted layer of plant material that is separate from the soil and will cause an indention in the soil if removed, "WL" represents % of ground covered by woody vegetation material, "Canopy Gap" represents % of vegetation canopy without vegetation cover, and "Veg Ht Variation" represents the variance in vegetation height in a sampling unit.

| Model | | delta AIC | df | Akaike weight |
|---|---|---|---|---|
| 42 | Grass+Duff+LU | 0.0 | 11 | 0.977017101 |
| 46 | Grass+Soil+LU | 7.5 | 11 | 0.02297724 |
| 17 | Flower+Duff+LU | 24.3 | 11 | 5.16683E-06 |
| 43 | Grass+Duff | 29.0 | 5 | 4.92756E-07 |
| 18 | Flower+Duff | 29.9 | 5 | 3.14195E-07 |
| 47 | Grass+Soil | 31.2 | 5 | 1.64024E-07 |
| 21 | Flower+Soil+LU | 31.8 | 11 | 1.21512E-07 |
| 22 | Flower+Soil | 32.7 | 5 | 7.74796E-08 |
| 44 | Grass+Duff+WL+LU | 298.9 | 15 | 1.21504E-65 |
| 50 | Grass+Duff+Canopy Gap+LU | 301.4 | 15 | 3.48116E-66 |
| 48 | Grass+Soil+WL+LU | 306.6 | 15 | 2.58558E-67 |
| 52 | Grass+Soil+Canopy Gap+LU | 308.1 | 15 | 1.22134E-67 |
| 19 | Flower+Duff+WL+LU | 323.2 | 15 | 6.4256E-71 |
| 25 | Flower+Duff+Canopy Gap+LU | 325.3 | 15 | 2.24856E-71 |
| 23 | Flower+Soil+WL+LU | 330.9 | 15 | 1.36735E-72 |
| 27 | Flower+Soil+Canopy Gap+LU | 332.0 | 15 | 7.88893E-73 |
| 51 | Grass+Duff+Canopy Gap | 334.8 | 7 | 1.94539E-73 |
| 53 | Grass+Soil+Canopy Gap | 336.4 | 7 | 8.74118E-74 |
| 45 | Grass+Duff+WL | 336.8 | 7 | 7.15668E-74 |
| 26 | Flower+Duff+Canopy Gap | 337.2 | 7 | 5.85939E-74 |
| 20 | Flower+Duff+WL | 337.2 | 7 | 5.85939E-74 |
| 49 | Grass+Soil+WL | 339.4 | 7 | 1.95042E-74 |
| 28 | Flower+Soil+Canopy Gap | 339.8 | 7 | 1.59687E-74 |
| 24 | Flower+Soil+WL | 340.4 | 7 | 1.18299E-74 |
| 32 | Grass+Soil+Canopy Gap+Veg Ht Variance+LU | 606.5 | 19 | 1.9503E-132 |
| 54 | Grass+EL+Canopy Gap+LU | 610.5 | 16 | 2.6394E-133 |
| 5 | Flower+Duff+Canopy Gap+Veg Ht Variance+LU | 623.8 | 19 | 3.4155E-136 |
| 7 | Flower+Soil+Canopy Gap+Veg Ht Variance+LU | 630.3 | 19 | 1.3243E-137 |

Table IV.18. Continued

| | | | | |
|---|---|---|---|---|
| 29 | Flower+EL+Canopy Gap+LU | 634.5 | 16 | 1.6217E-138 |
| 55 | Grass+EL+Canopy Gap | 638.3 | 8 | 2.4256E-139 |
| 30 | Flower+EL+Canopy Gap | 641.4 | 8 | 5.1483E-140 |
| 31 | Grass+Duff+Canopy Gap+Veg Ht Variance | 642.7 | 9 | 2.6876E-140 |
| 33 | Grass+Soil+Canopy Gap+Veg Ht Variance | 644.1 | 9 | 1.3346E-140 |
| 6 | Flower+Duff+Canopy Gap+Veg Ht Variance | 644.5 | 9 | 1.0927E-140 |
| 8 | Flower+Soil+Canopy Gap+Veg Ht Variance | 646.5 | 9 | 4.0199E-141 |
| 36 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance+LU | 898.9 | 23 | 6.2553E-196 |
| 34 | Grass+EL+Canopy Gap+Veg Ht Variance+LU | 908.8 | 20 | 4.4309E-198 |
| 11 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance+LU | 922.8 | 23 | 4.0404E-201 |
| 13 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU | 929.2 | 23 | 1.647E-202 |
| 15 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU | 929.2 | 23 | 1.647E-202 |
| 9 | Flower+EL+Canopy Gap+Veg Ht Variance+LU | 932.8 | 20 | 2.7224E-203 |
| 35 | Grass+EL+Canopy Gap+Veg Ht Variance | 945.8 | 10 | 4.093E-206 |
| 10 | Flower+EL+Canopy Gap+Veg Ht Variance | 947.9 | 10 | 1.4323E-206 |
| 37 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance | 951.1 | 11 | 2.8918E-207 |
| 39 | Grass+Soil+WL+Canopy Gap+Veg Ht Variance | 952.5 | 11 | 1.436E-207 |
| 12 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance | 952.7 | 11 | 1.2993E-207 |
| 14 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance | 954.9 | 11 | 4.3252E-208 |
| 16 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance | 954.9 | 11 | 4.3252E-208 |
| 4 | Null | 1562.3 | 1 | 0 |
| 3 | LU | 1828.2 | 3 | 0 |
| 2 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+ Veg Ht Variance | 1836.9 | 10 | 0 |
| 1 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+ Veg Ht Variance+LU | 2125.9 | 39 | 0 |

Table IV.19. AIC values for path models explaining pollinator species richness using September data for CRP, croplands, native grasslands, and vegetation characteristics in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. "LU" represents land use, either CRP and native grassland or CRP and cropland, "Flower" represents % flower cover, "Grass" represents % grass cover, "Forb" represents % non-flowering forb cover, "Soil" represents % of ground covered by bare soil, "Duff" represents % of ground covered by duff, defined as loose plant material that is not a separate layer from soil, "EL" represents % of ground covered by embedded litter, defined as a compacted layer of plant material that is separate from the soil and will cause an indention in the soil if removed, "WL" represents % of ground covered by woody vegetation material, "Canopy Gap" represents % of vegetation canopy without vegetation cover, and "Veg Ht Variation" represents the variance in vegetation height in a sampling unit.

| | Model | delta AIC | df | Akaike weight |
|---|---|---|---|---|
| 42 | Grass+Duff+LU | 0.0 | 11 | 0.98014635 |
| 46 | Grass+Soil+LU | 7.8 | 11 | 0.019840036 |
| 17 | Flower+Duff+LU | 22.4 | 11 | 1.34027E-05 |
| 21 | Flower+Soil+LU | 30.7 | 11 | 2.11286E-07 |
| 18 | Flower+Duff | 34.7 | 5 | 2.85944E-08 |
| 43 | Grass+Duff | 36.6 | 5 | 1.10586E-08 |
| 22 | Flower+Soil | 38.0 | 5 | 5.49156E-09 |
| 47 | Grass+Soil | 39.9 | 5 | 2.12381E-09 |
| 44 | Grass+Duff+WL+LU | 298.4 | 15 | 1.56514E-65 |
| 50 | Grass+Duff+Canopy Gap+LU | 304.2 | 15 | 8.61192E-67 |
| 48 | Grass+Soil+WL+LU | 306.3 | 15 | 3.01364E-67 |
| 52 | Grass+Soil+Canopy Gap+LU | 311.1 | 15 | 2.73391E-68 |
| 19 | Flower+Duff+WL+LU | 321.4 | 15 | 1.58551E-70 |
| 25 | Flower+Duff+Canopy Gap+LU | 323.5 | 15 | 5.54828E-71 |
| 27 | Flower+Soil+Canopy Gap+LU | 329.5 | 15 | 2.76233E-72 |
| 23 | Flower+Soil+WL+LU | 329.8 | 15 | 2.37756E-72 |
| 20 | Flower+Duff+WL | 341.5 | 7 | 6.84712E-75 |
| 26 | Flower+Duff+Canopy Gap | 342.5 | 7 | 4.15299E-75 |
| 45 | Grass+Duff+WL | 342.9 | 7 | 3.40018E-75 |
| 51 | Grass+Duff+Canopy Gap | 344.8 | 7 | 1.31499E-75 |
| 24 | Flower+Soil+WL | 345.1 | 7 | 1.13182E-75 |
| 28 | Flower+Soil+Canopy Gap | 345.4 | 7 | 9.74168E-76 |
| 49 | Grass+Soil+WL | 346.6 | 7 | 5.34635E-76 |
| 53 | Grass+Soil+Canopy Gap | 347.7 | 7 | 3.08457E-76 |
| 32 | Grass+Soil+Canopy Gap+Veg Ht Variance+LU | 609.3 | 19 | 4.8248E-133 |
| 54 | Grass+EL+Canopy Gap+LU | 613.4 | 16 | 6.2112E-134 |
| 5 | Flower+Duff+Canopy Gap+Veg Ht Variance+LU | 621.9 | 19 | 8.8598E-136 |

Table IV.19. Continued

| | | | | |
|---|---|---|---|---|
| 7 | Flower+Soil+Canopy Gap+Veg Ht Variance+LU | 628.0 | 19 | 4.1959E-137 |
| 29 | Flower+EL+Canopy Gap+LU | 632.3 | 16 | 4.8875E-138 |
| 30 | Flower+EL+Canopy Gap | 647.1 | 8 | 2.9875E-141 |
| 55 | Grass+EL+Canopy Gap | 649.2 | 8 | 1.0454E-141 |
| 6 | Flower+Duff+Canopy Gap+Veg Ht Variance | 649.9 | 9 | 7.3671E-142 |
| 31 | Grass+Duff+Canopy Gap+Veg Ht Variance | 652.1 | 9 | 2.4523E-142 |
| 8 | Flower+Soil+Canopy Gap+Veg Ht Variance | 652.2 | 9 | 2.3327E-142 |
| 33 | Grass+Soil+Canopy Gap+Veg Ht Variance | 654.4 | 9 | 7.7649E-143 |
| 36 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance+LU | 901.3 | 23 | 1.8901E-196 |
| 38 | Grass+Soil+WL+Canopy Gap+Veg Ht Variance+LU | 908.2 | 23 | 6.0002E-198 |
| 34 | Grass+EL+Canopy Gap+Veg Ht Variance+LU | 911.6 | 20 | 1.0961E-198 |
| 11 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance+LU | 920.9 | 23 | 1.0481E-200 |
| 13 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU | 927.0 | 23 | 4.9636E-202 |
| 15 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance+LU | 927.0 | 23 | 4.9636E-202 |
| 9 | Flower+EL+Canopy Gap+Veg Ht Variance+LU | 930.7 | 20 | 7.8047E-203 |
| 10 | Flower+EL+Canopy Gap+Veg Ht Variance | 953.7 | 10 | 7.9062E-208 |
| 35 | Grass+EL+Canopy Gap+Veg Ht Variance | 955.6 | 10 | 3.0576E-208 |
| 12 | Flower+Duff+WL+Canopy Gap+Veg Ht Variance | 957.8 | 11 | 1.0178E-208 |
| 37 | Grass+Duff+WL+Canopy Gap+Veg Ht Variance | 959.6 | 11 | 4.1381E-209 |
| 14 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance | 960.4 | 11 | 2.7738E-209 |
| 16 | Flower+Soil+WL+Canopy Gap+Veg Ht Variance | 960.4 | 11 | 2.7738E-209 |
| 39 | Grass+Soil+WL+Canopy Gap+Veg Ht Variance | 962.5 | 11 | 9.7067E-210 |
| 4 | Null | 1568.4 | 1 | 0 |
| 3 | LU | 1830.4 | 3 | 0 |
| 2 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+ Veg Ht Variance | 1845.2 | 10 | 0 |
| 1 | Grass+Forb+Flower+Soil+Duff+WL+EL+Canopy Gap+ Veg Ht Variance+LU | 2125.9 | 39 | 0 |

Figure IV.15. Model 42: Path Analysis of the observed effects of CRP (CRP), cropland (AG), percent grass cover (GRA) and percent duff cover (DUF) on pollinator abundance (ABU) using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Significant pathways are designated with *. Variance not explained by factors in the diagram are indicated by ▪ .

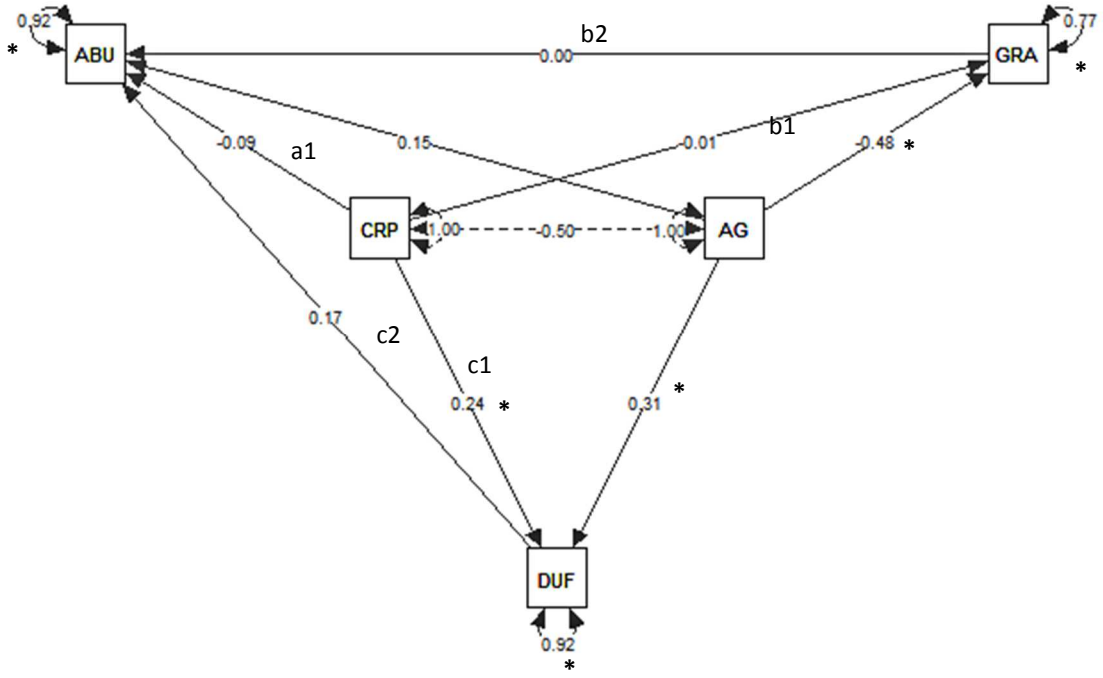


Figure IV.16. Model 42: Path Analysis of the observed effects of CRP (CRP), native grassland (NG), percent grass cover (GRA) and percent duff cover (DUF) on pollinator abundance (ABU) using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Significant pathways are designated with *. Variance not explained by factors in the diagram are indicated by ▪ .

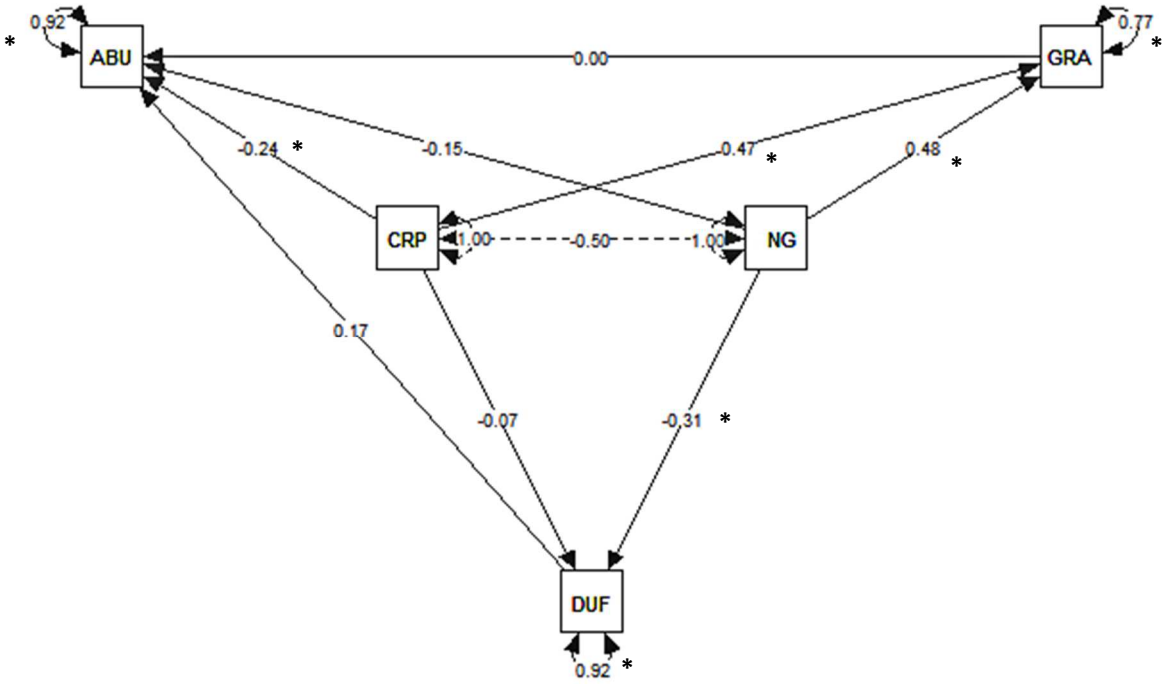


Figure IV.17. Model 42: Path Analysis of the observed effects of CRP, (CRP) cropland (AG), percent grass cover (GRA) and percent duff cover (DUF) on pollinator species richness (SRT) using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Significant pathways are designated with *. Variance not explained by factors in the diagram are indicated by ▪ .

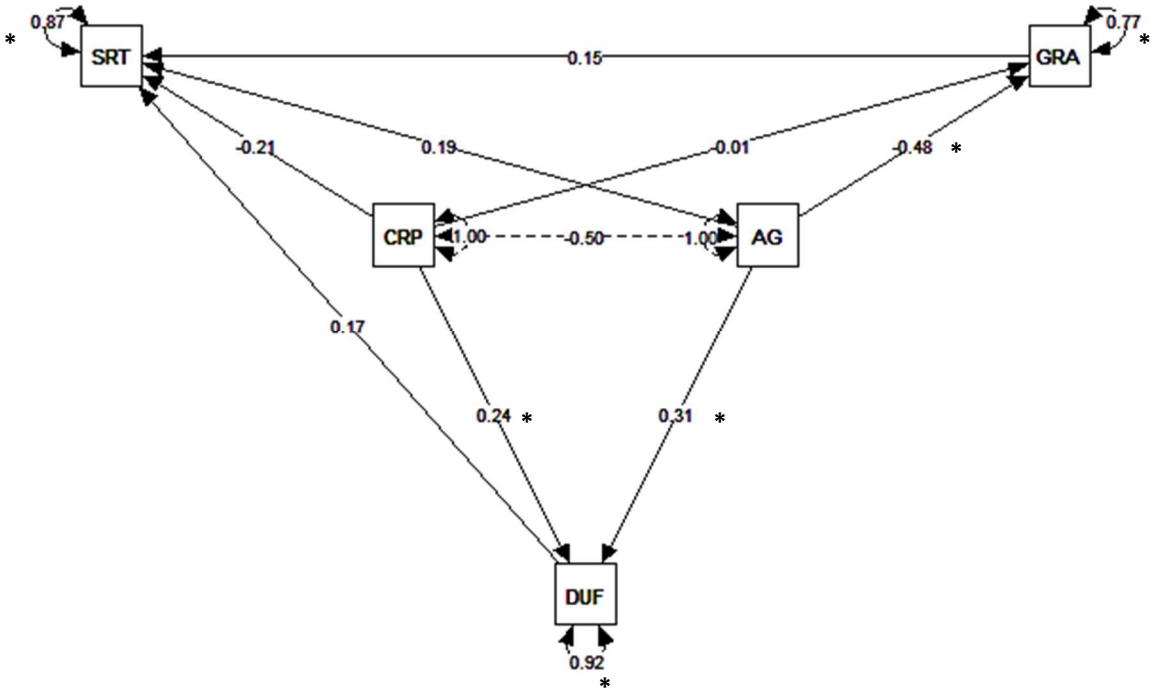


Figure IV.18. Model 42: Path Analysis of the observed effects of CRP (CRP), native grassland (NG), percent grass cover (GRA) and percent duff cover (DUF) on pollinator species richness (SRT) using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Significant pathways are designated with *. Variance not explained by factors in the diagram are indicated by ▪ .

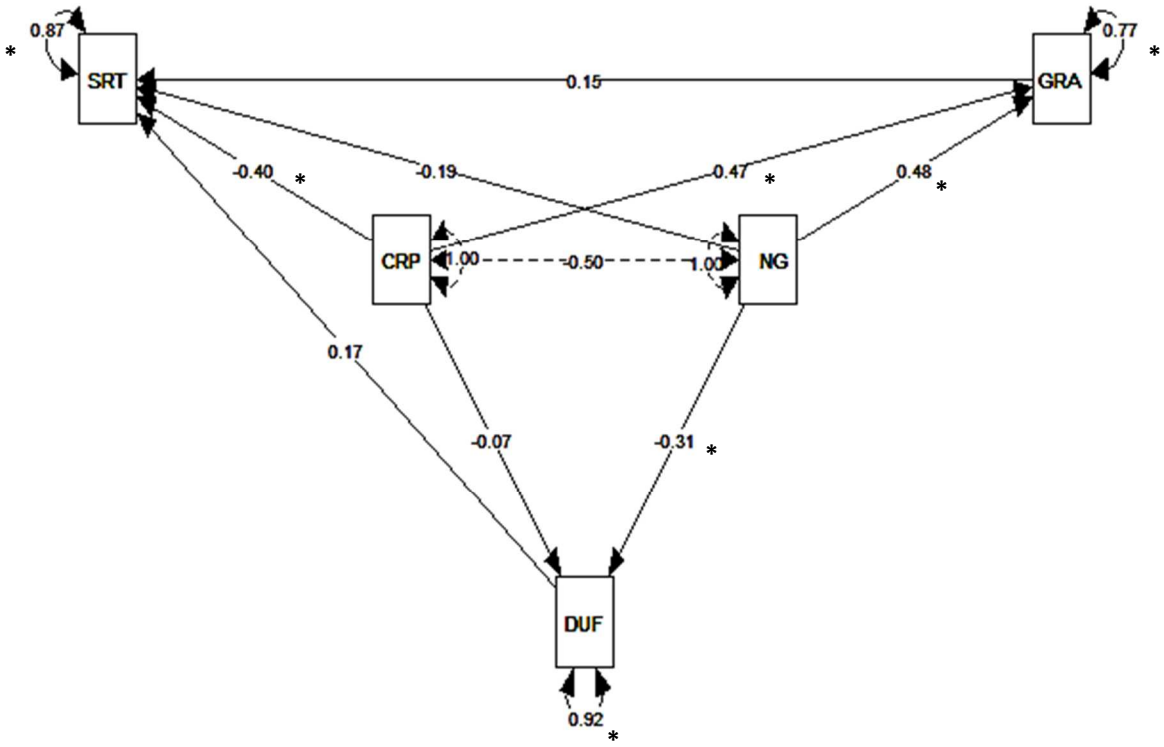


Table IV.20. Path Analysis Model 42: Strengths of the observed direct, indirect and total effects of CRP, cropland native grassland, percent grass cover and percent duff cover on pollinator abundance and species richness using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. a. Effects of CRP, cropland, and vegetation characteristics on pollinator abundance in late season, b. Effects of CRP, native grasslands, and vegetation characteristics on pollinator abundance in late season, c. Effects of CRP, cropland, and vegetation characteristics on pollinator species richness in late season, d. Effects of CRP, native grasslands and vegetation characteristics on pollinator species richness in late season. There were no indirect effects for % grass cover and % duff cover (-). The indirect effects of land use through % grass cover and % duff cover are indicated by (G) graminoid, (D) duff.

**a. Effects of CRP, cropland, and vegetation characteristics on pollinator abundance in late season**

| | Direct Effect | Indirect Effect | Total Effect |
|---|---|---|---|
| **CRP** | -0.089 | G:-0.014 x 0.003 = -0.000042<br>D:0.242 x 0.172 = 0.041624<br>0.041582 | -0.047418 |
| **Cropland** | 0.153 | G:-0.483 x 0.003 = -0.001449<br>D:0.313 x 0.172 = 0.053836<br>0.052387 | 0.205387 |
| **% Grass** | 0.003 | - | 0.003 |
| **% Duff** | 0.172 | - | 0.172 |

**b. Effects of CRP, native grasslands, and vegetation characteristics on pollinator abundance in late season**

| | Direct Effect | Indirect Effect | Total Effect |
|---|---|---|---|
| **CRP** | -0.242 | G:0.469 x 0.003 = 0.001407<br>D:-0.071 x 0.172 = -0.012212<br>-0.010805 | -0.252805 |
| **Native Grassland** | -0.153 | G:0.483 x 0.003 = 0.001449<br>D:-0.313 x 0.172 = -0.053836<br>0.052387 | -0.100613 |
| **% Grass** | 0.003 | - | 0.003 |
| **% Duff** | 0.172 | - | 0.172 |

**c. Effects of CRP, cropland, and vegetation characteristics on pollinator species richness in late season**

| | Direct Effect | Indirect Effect | Total Effect |
|---|---|---|---|
| **CRP** | -0.207 | G:-0.014 x 0.147 = -0.002058<br>D:0.242 x 0.166 = 0.040172<br>0.038114 | -0.169 |
| **Cropland** | 0.191 | G:-0.483 x 0.147 = -0.071001<br>D:0.313 x 0.166 = 0.051958<br>-0.019043 | 0.171 |
| **% Grass** | 0.147 | - | 0.147 |
| **% Duff** | 0.166 | - | 0.166 |

Table IV.20 Continued

**d. Effects of CRP, native grasslands and vegetation characteristics on pollinator species richness in late season**

| | Direct Effect | Indirect Effect | Total Effect |
|---|---|---|---|
| **CRP** | -0.398 | G:0.469 x 0.147 = 0.068943<br>D:-0.071 x 0.166 = -0.011786<br>0.057157 | -0.340843 |
| **Native Grassland** | -0.191 | G:0.483 x 0.147 = 0.071001<br>D:-0.313 x 0.166 = -0.051958<br>0.019043 | -0.172 |
| **% Grass** | 0.147 | - | 0.147 |
| **% Duff** | 0.166 | - | 0.166 |

Table IV.21. Path Analysis of the observed effects of CRP, native grassland, percent grass cover and percent duff cover on pollinator species richness using data collected late season in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. Significant ($p<0.05$) pathways are designated with *. Cropland (AG), CRP (CRP), native grassland (NG), graminoid (GRA), duff (DUFF), abundance (ABU), richness (SR).

| Model | Path | p value | z score | path coefficient |
|---|---|---|---|---|
| ***September Abundance*** | GRA → ABU | 0.980 | 0.025 | 0.003 |
| **AG/CRP** | DUFF → ABU | 0.073 | 1.792 | 0.0172 |
| | CRP → ABU | 0.414 | -0.817 | -0.089 |
| | AG ↔ ABU | 0.208 | 1.259 | 0.153 |
| | CRP ↔ GRA | 0.890 | -0.139 | -0.014 |
| | AG → GRA* | <0.000 | -4.942 | -0.483 |
| | CRP → DUFF* | 0.023 | 2.275 | 0.242 |
| | AG → DUFF* | 0.003 | 2.937 | 0.313 |
| | DUFF* | <0.000 | 7.348 | 0.919 |
| | GRA* | <0.000 | 7.348 | 0.773 |
| | ABU* | <0.000 | 7.348 | 0.918 |
| ***September Abundance*** | GRA → ABU | 0.980 | 0.025 | 0.003 |
| **NG/CRP** | DUFF → ABU | 0.073 | 1.792 | 0.172 |
| | CRP → ABU* | 0.039 | -2.062 | -0.242 |
| | NG ↔ ABU | 0.208 | -1.259 | -0.153 |
| | CRP ↔ GRA* | <0.000 | 4.803 | 0.469 |
| | NG → GRA* | <0.000 | 4.942 | 0.483 |
| | CRP → DUFF | 0.508 | -0.662 | -0.071 |
| | NG → DUFF* | 0.003 | -2.937 | -0.313 |
| | DUFF* | <0.000 | 7.348 | 0.919 |
| | GRA* | <0.000 | 7.348 | 0.733 |
| | ABU* | <0.000 | 7.348 | 0.918 |
| ***September Richness*** | GRA → SR | 0.515 | -1.437 | 0.147 |
| **AG/CRP** | DUFF → SR | 0.077 | 1.769 | 0.166 |
| | CRP → SR | 0.052 | -1.945 | -0.207 |
| | AG ↔ SR | 0.106 | 1.614 | 0.191 |
| | CRP ↔ GRA | 0.890 | -0.139 | -0.014 |
| | AG → GRA* | <0.000 | -0.483 | -4.942 |
| | CRP → DUFF* | 0.023 | 2.275 | 0.242 |
| | AG → DUFF* | 0.003 | 2.937 | 0.313 |
| | DUFF* | <0.000 | 7.348 | 0.919 |
| | GRA* | <0.000 | 7.348 | 0.773 |
| | SR* | <0.000 | 7.348 | 0.871 |

Table IV.21. Continued

| Model | Path | p value | z score | path coefficient |
|---|---|---|---|---|
| ***September Richness*** | GRA → SR | 0.151 | 1.437 | 0.147 |
| **NG/CRP** | DUFF → SR | 0.077 | 1.769 | 0.166 |
| | CRP → SR* | 0.001 | -3.477 | -0.398 |
| | NG ↔ SR | 0.106 | -1.614 | -0.191 |
| | CRP ↔ GRA* | <0.0001 | 4.803 | 0.469 |
| | NG → GRA* | <0.0001 | 4.942 | 0.483 |
| | CRP → DUFF | 0.508 | -0.662 | -0.071 |
| | NG → DUFF* | 0.003 | -2.937 | -0.313 |
| | DUFF* | <0.0001 | 7.348 | 0.919 |
| | GRA* | <0.0001 | 7.348 | 0.773 |
| | SR* | <0.0001 | 7.348 | 0.871 |

Figure IV.19. Ordination diagram for partial redundancy analysis (pRDA) for 17 pollinator groups, 10 vegetation characteristics, 3 land uses, and 2 land types using trap and vegetation data collected in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. C-Coleoptera, HAn-Andrendiae, HAp-Apidae, HC-Colletidae, HH-Halictidae, HM-Megachilidae, HMe-Melittidae, HCh-Chalcidae, Hpw-parasitic wasps, Hsw-sphecid wasps, HV-vespid wasps, HO-other Hymenoptera, DB-Bombyllidae, DS-Syrphidae, DO-other dipterans, L-Lepidoptera, O-other invertebrates, GRAM-grass, FLOWER-flowering forb, FORB-non-flowering forb, WL-woody litter, EL-embedded litter, SOILS-bare soil, DUFF-duff, GAP-canopy gap, VEGHTVAR-vegetation height variance, VEGHTMEA-vegetation height mean, AG-cropland, CRP, RNG-native grasslands, P-playa, U-uplands.

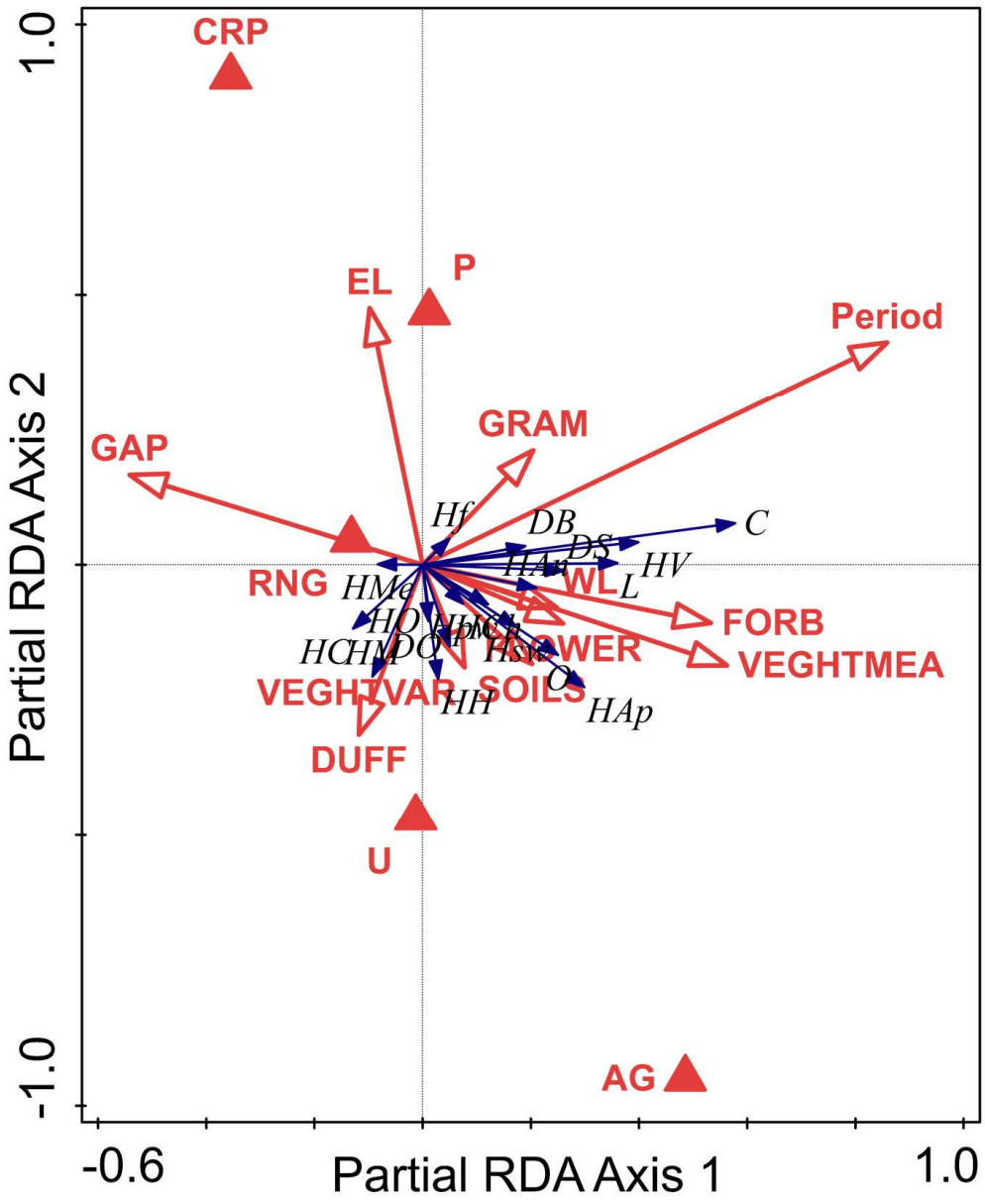
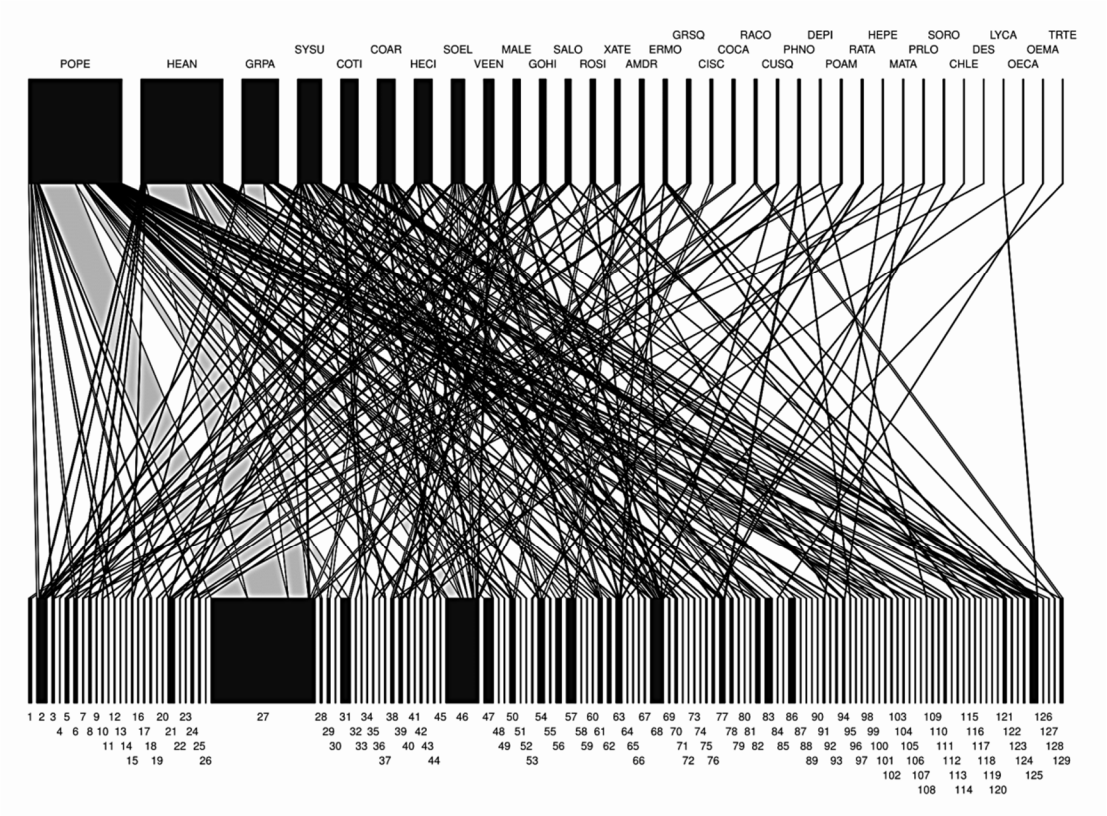


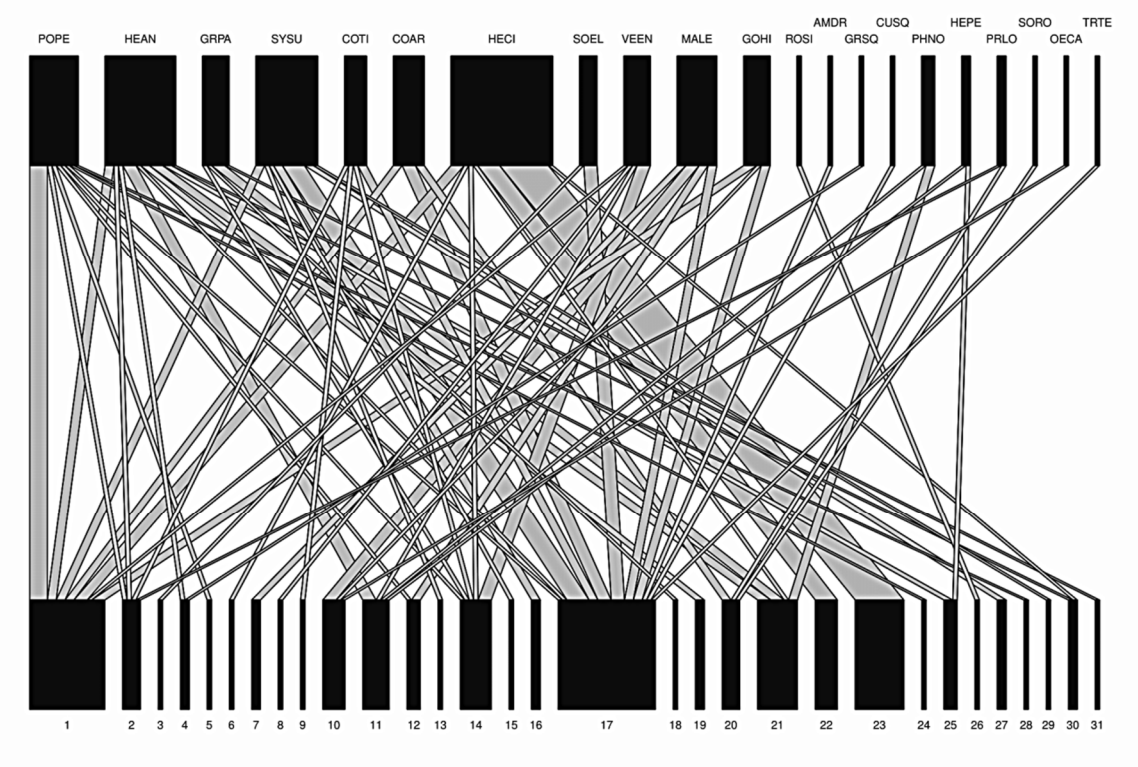
Figure IV.20. Bipartite networks illustrating flower visitation by potential pollinators from the insect orders Hymenoptera, Diptera, Coleoptera and Lepidoptera in croplands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.




1) *Acmaeodera* sp. 2) *Agapostemon angelicus* 3) *Agapostemon angelicus/texanus* 4) *Agapostemon coloradinus* 5) *Allograpta exotica* 6) *Allograpta obliqua* 7) Alticini 8) *Anastoechus* sp. 9) *Anopliomorpha rinconium* 10) *Anthophorisca* sp. 11) *Anthophorula* sp. 12) *Archytas* sp. 13) Argidae 14) *Asterocampa celtis* 15) *Atalopedes campestris* 16) *Augochlorella aurata* 17) *Augochloropsis metallica* 18) *Bembix* sp. 19) *Botanophila sp*. 20) *Bothrotes* sp. 21) Braconidae 22) *Brephidium exilis* 23) Calliphoridae 24) *Catharosia* sp. 25) *Cerceris* sp. 26) *Chaetocnema* sp. 27) *Chauliognathus basalis* 28) *Chauliognathus limbicollis* 29) *Chauliognathus scutellaris* 30) Cheloninae 31) Chloropidae 32) *Coelioxys* sp. 33) *Colletes* sp. 34) *Collops* sp. 35) Crambidae 36) *Cylindromyia sp*. 37) *Diabrotica undecimpunctata* 38) *Diadasia diminuta* 39) *Diadasia enavata* 40) *Diadasia ochracea* 41) Diptera 42) *Drapetis* sp. 43) *Echinargus isola* 44) *Elachista* sp. 45) Epeolus sp. 46) *Epicauta* sp. 47) *Eristalis stipator* 48) *Estoloides* sp. 49) *Eucerceris* sp. 50) *Eugnoriste* sp. 51) *Eupoeodes volucris* 52) *Euptoieta claudia* 53) *Fannia* sp. 54) Formicidae 55) Gelechiinae 56) *Geron* sp. 57) *Gnathium* sp. 58) *Gonia* sp. 59) *Graphomya* sp. 60) *Grymnosoma* sp. 61) *Halictus ligatus* 62) *Haplorhynchites* sp. 63) Helionidae 64) *Hippodamia convergens* 65) *Holcopasites calliopsidis* 66) Ichneumonidae 67) *Lasioglossum* sp. 68) *Lasioglossum Dialictus* 69) *Lathyrophthalmus aeneus* 70) Lepidoptera 71) *Lerodea eufala* 72) *Leucophora* sp. 73) *Lytta* sp. 74) *Megachile parallela* 75) *Melissodes agilis* 76) *Melissodes communis* 77) *Melissodes coreopsis* 78) *Melissodes tristis* 79) *Mordella* sp. 80) Muscidae 81) Myzininae 82) *Nathalis iole* 83) *Nemognatha* sp. 84) *Neomyia cornicina* 85)

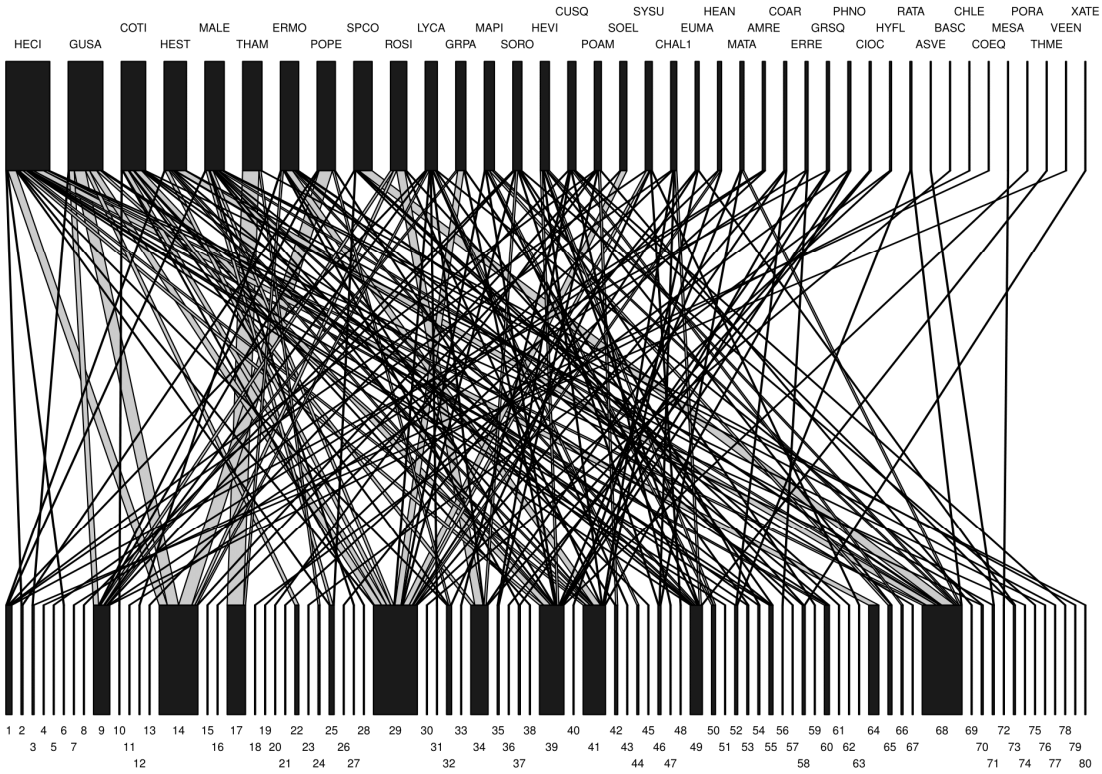
Noctuidae 86*) Nomada* sp. 87) *Nomia cornicina* 88) *Ozodiceromya* sp. 89) *Palpada vinetorum* 90) *Paravilla* sp. 91) *Perdita Cockerellia* 92) *Perdita Perdita* 93) *Philanthus* sp. 94) *Pholisora catullus* 95) *Phyciodes phaon* 96) *Phyciodes picta* 97) *Phyciodes tharos* 98) *Poecilanthrax* sp. 99) *Poecilognathus* sp. 100) *Poecilopompilus* sp. 101) Pompilinae 102) *Pontia protodice* 103) *Prionyx* sp. 104) *Protandrena Heterosarus* 105) *Protandrena Protandrena* 106) *Protandrena Pterosarus* 107) *Pseudodoros clavatus* 108) *Ptilodexia* sp. 109) Pyralidae 110) *Pyrgus communis* 111) *Pyrota* sp. 112) *Ravinia* sp. 113) Sacrophagidae 114) Scoliinae 115) *Scymnus* sp. 116) *Sepsidimorpha* sp. 117) *Sphaenothecus bivittatus* 118) *Stenodynerus* sp. 119) *Stizoides renicinctus* 120) *Syritta flaviventris* 121) Tachinidae 122) *Tetraloniella spissa* 123) Tiphiinae 124) Torymidae 125) *Toxomerus* sp. 126) *Triepeolus* sp. 127) *Vanessa atalanta* 128) *Zodion* sp. 129) *Zonitis* sp.

Figure IV.21. Bipartite networks illustrating flower visitation by bees in croplands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.



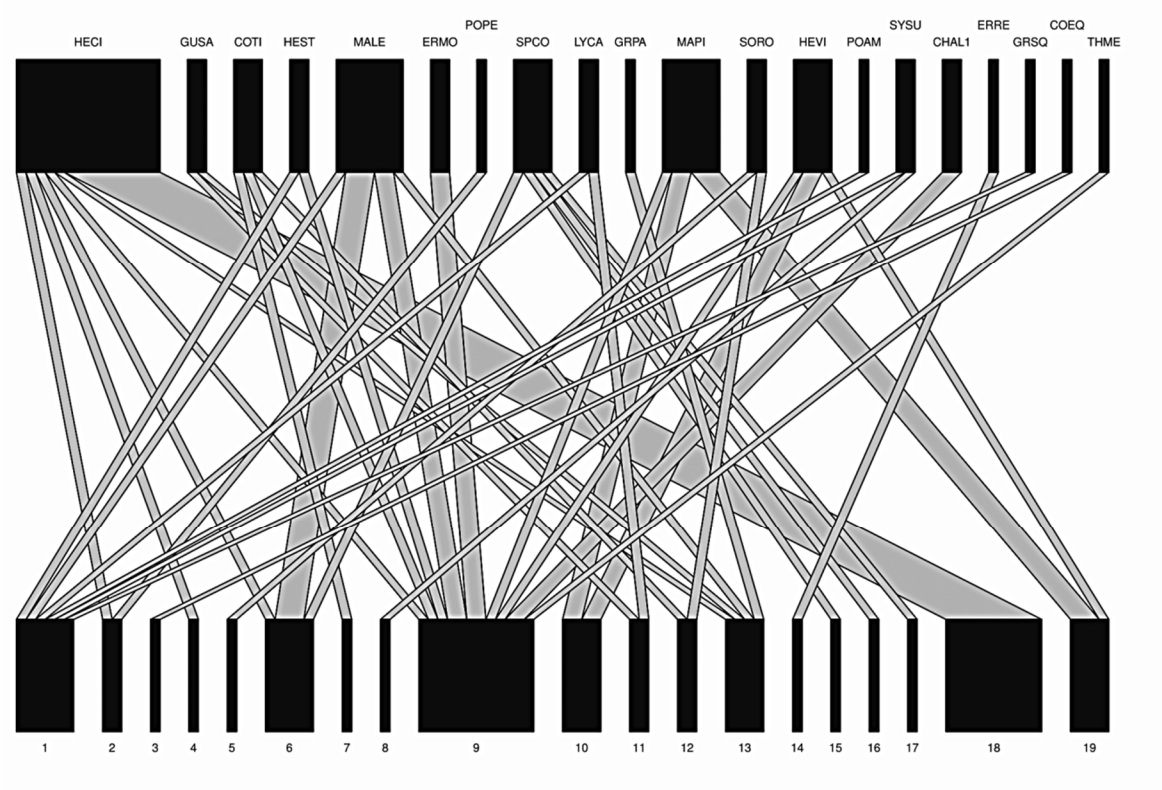

1) *Agapostemon angelicus* 2) *Agapostemon angelicus/texanus* 3) *Agapostemon coloradinus* 14) *Anthophorula* (*Anthophorisca)* sp. 15) *Anthophorula* sp. 6) *Augochlorella aurata* 7) *Augochloropsis metallica* 8) *Coelioxys* sp. 9) *Colletes* sp. 10) *Diadasia diminuta* 11) *Diadasia enavata* 12) *Diadasia ochracea* 13) *Epeolu*s sp. 14) *Halictus ligatus* 15) *Holcopasites calliopsidis* 16) *Lasioglossum* sp. 17) *Lasioglossum Dialictus* 18) *Megachile parallela* 19) *Melissodes agilis* 20) *Melissodes communis* 21) *Melissodes coreopsis* 22) *Melissodes tristis* 23*) Nomada* sp. 24) *Nomia cornicina* 25) *Perdita Cockerellia* 26) *Perdita Perdita* 27) *Protandrena Heterosarus* 28) *Protandrena Protandrena* 29) *Protandrena Pterosarus* 30)*Tetraloniella spissa* 31) *Triepeolus* sp.

Figure IV.22. Bipartite networks illustrating flower visitation by potential pollinators from the insect orders Hymenoptera, Diptera, Coleoptera and Lepidoptera in CRP fields in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.



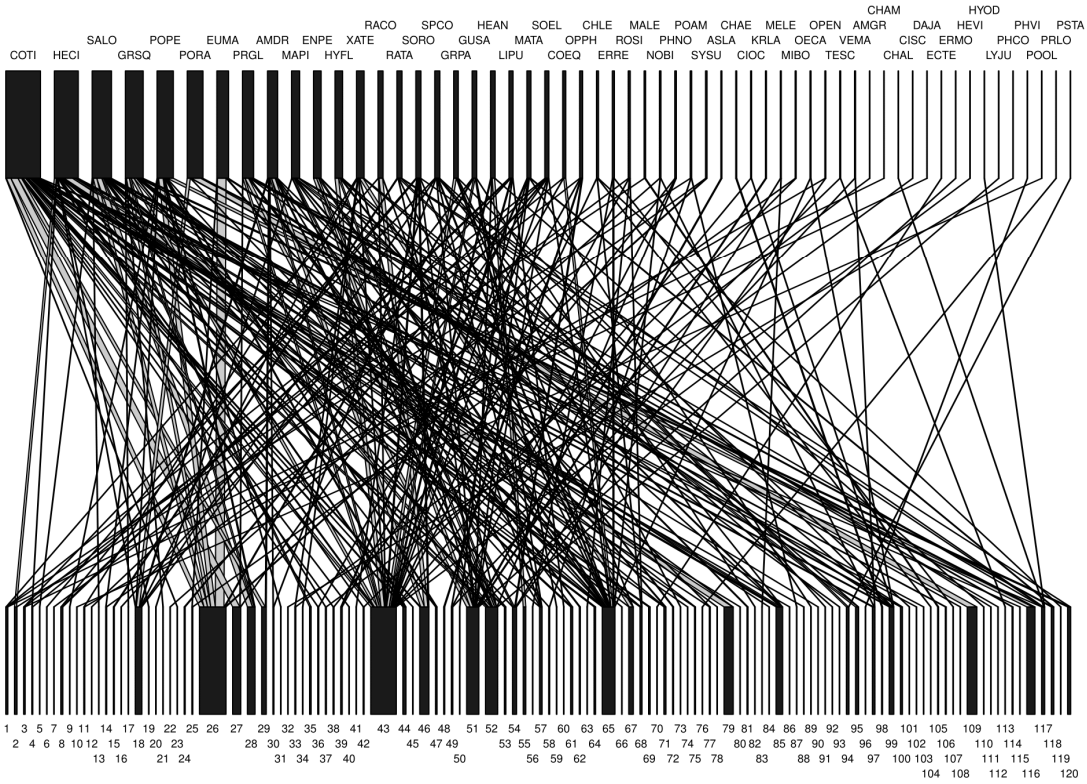

1) *Agapostemon angelicus* 2) *Agapostemon angelicus/texanus* 3) *Anastoechus* sp. 4) *Ancyloscelis sejunctus* 5) *Angioneura* sp. 6) *Anthidium porterae* 7) Argidae 8) *Bombus pensylvanicus* 9) Braconidae 10) *Brephidium exilis* 11) *Campiglossa* sp. 12) *Catharosia* sp. 13) *Cerceris* sp. 14) *Chauliognathus basalis* 15) Cheloninae 16) *Chetogena* sp. 17) Chloropidae 18) *Chrysanthrax* sp. 19) *Colias eurytheme* 20) Crabronini 21) Crambidae 22) *Crossidius sp*. 23) *Crossidius sayi bilenticulatus* 24) Curculonidae 25) *Diadasia diminuta* 26) *Drapetis* sp. 27) *Elachista* sp. 28) *Epeolus* sp. 29) *Epicauta* sp. 30) *Epicauta maculata* 31) Erebidae 32) *Eristalis stipator* 33) *Eucerceris* sp. 34) *Eugnoriste* sp. 35) *Euodynerus* sp. 36) *Euphoria kernii* 37) Formicidae 38) Gelechiidae 39) *Geron* sp. 40) *Gnathium* sp. 41) Helionidae 42) *Helophilus* sp. 43) *Heteropogon* sp. 44) *Heterostylum* sp. 45) *Hyles lineata* 46) Ichneumonidae 47) Larrini 48) *Lasioglossum* sp. 49) *Lasioglossum Dialictus* 50) *Lasioglossum Hexaperdita* 51) *Lepidanthrax* sp. 52) Lepidoptera 53) *Melissodes* sp. 54) *Melissodes communis* 55) *Melissodes coreopsis* 56) *Melissodes rivalis* 57) *Melissodes tristis* 58) *Mordella* sp. 59) Muscidae 60) *Nathalis iole* 61) *Panurginus* sp. 62) *Panurginus beardsleyii* 63) *Paravilla* sp. 64) *Perdita Cockerellia* 65) *Perdita Hexaperdita* 66) *Philanthus* sp. 67) *Phycoides picta* 68) *Poecilognathus* sp. 69) *Polistes* sp. 70) *Pontia protodice* 71) *Prionyx* sp. 72) *Pterocheilus* sp. 73) Pyralidae 74) *Pyrgus communis* 75) Sarcophagidae 76) *Stenodynerus* sp. 77) *Stenopodius* sp. 78) *Stizoides renicinctus* 79) Tachinidae 80) *Toxomerus* sp.

Figure IV.23. Bipartite networks illustrating flower visitation by bees in CRP fields in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.




1) *Agapostemon angelicus* 2) *Agapostemon angelicus/texanus* 3) *Ancyloscelis sejunctus* 4) *Anthidium porterae* 5) *Bombus pensylvanicus* 6) *Diadasia diminuta* 7) *Epeolus* sp. 8) *Lasioglossum* sp. 9) *Lasioglossum Dialictus* 10) *Lasioglossum Hexaperdita* 11) *Melissodes* sp. 12) *Melissodes communis* 13) *Melissodes coreopsis* 14) *Melissodes rivalis* 15) *Melissodes tristis* 16) *Panurginus* sp. 17) *Panurginus beardsleyii* 18) *Perdita Cockerellia* 19) *Perdita Hexaperdita*

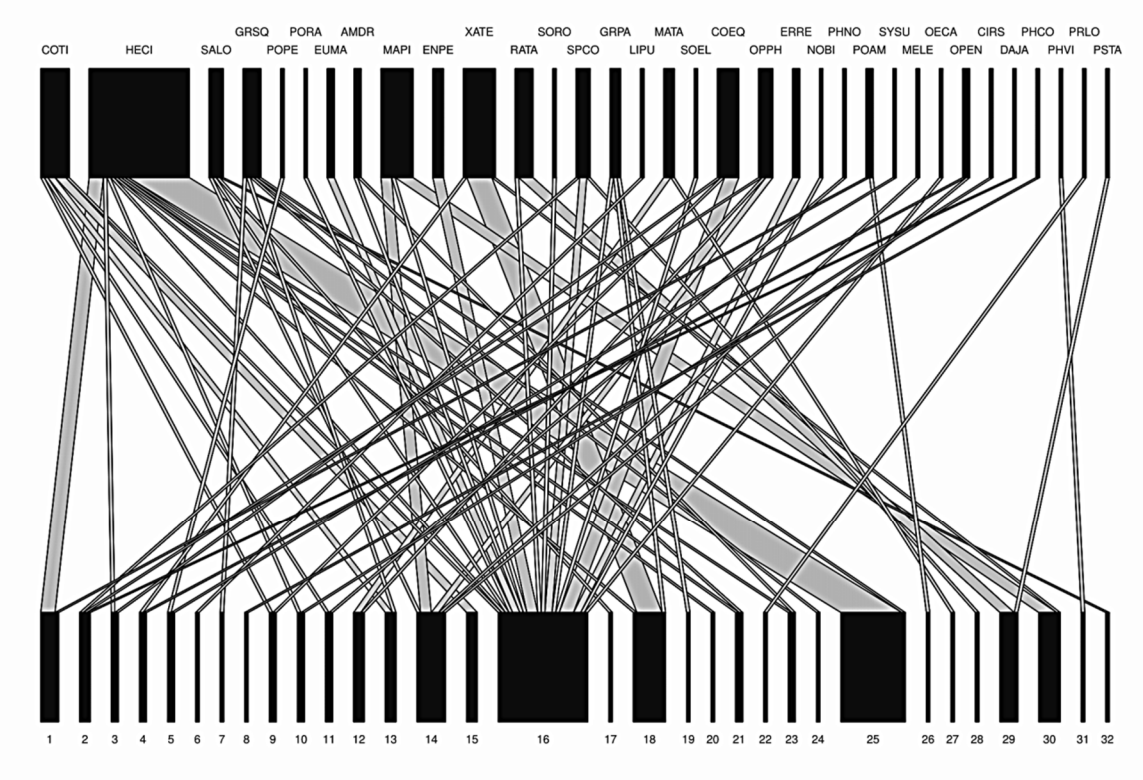
Figure IV.24. Bipartite networks illustrating flower visitation by potential pollinators from the insect orders Hymenoptera, Diptera, Coleoptera and Lepidoptera in native grasslands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.




1) *Acmaeodera* sp. 2) *Agapostemon angelicus* 3) *Agapostemon angelicus/texanus* 4) *Agapostemon texanus* 5) *Allograpta exotica* 6) Alticini 7) Ammophilinae 8) *Anastoechus* sp. 9) *Archytas* sp. 10) Argidae 11) *Ashmeadiella gilletei* 12) *Astata sp*. 13) *Atalopedes campestris* 14) *Augochloropsis metallica* 15) *Batyle* sp. 16) *Bombus pensylvanicus* 17) Bothrotes sp. 18) Braconidae 19) *Brephidium exilis* 20) Buprestidae 21) *Calliopsis coloradensis* 22) Calliphoridae 23) *Campiglossa* sp. 24) Carabidae 25) *Cerceris* sp. 26) *Chauliognathus basilis* 27) *Chauliognathus scutellaris* 28) *Chauliognathus limbicollis* 29) Chloropidae 30) Chrysomelidae 31) *Cochliomyia* sp. 32) *Colletes* sp. 33) *Collops* sp. 34) *Crossidius* sp. 35) *Diabrotica undecimpunctata* 36) *Diadasia diminuta* 37) *Diadasia enavata* 38) *Diadasia ochracea* 39) *Diadasia rinconis* 40) *Disonycha triangularis* 41) *Drapetis* sp. 42) *Echinargus isola* 43) *Epicauta* sp. 44) *Eristalis stipator* 45) *Eucerceris* sp. 46) *Eugnoriste* sp. 47) *Euodynerus* sp. 48) *Euphoria kernii* 49) *Euptoieta claudia* 50) *Exoprosopa* sp. 51) Formicidae 52) *Geron* sp. 53) *Halictus ligatus* 54) *Halictus tripartitus* 55) *Haplorhynchites* sp. 56) Heleomyzidae 57) Helionidae 58) *Helophilus* sp. 59) Hemerobiidae 60) *Heteropogon* sp. 61) *Hippodamia convergens* 62) *Hymenorus* sp. 63) Ichneumonidae 64) *Lasioglossum* sp. 65) *Lasioglossum Dialictus* 66) *Lasioglossum Evylaeus* 67) *Lasioglossum Hexaperdita* 68) Lepidoptera 69) *Leucophora* sp. 70) *Listrus* sp. 71) *Lordotus* sp. 72) *Lytta biguttata* 73) *Megachile parallela* 74) *Megachile policaris* 75) *Melissodes* sp. 76) *Melissodes communis* 77) *Melissodes coreopsis* 78) *Melissodes*

*submenuacha* 79) *Melissodes tristis* 80) *Microchaetina* sp. 81) *Mordella* sp. 82) Mutillidae 83) *Mythicomyia* sp. 84) Myzininae 85) *Nathalis iole* 86) *Nemognatha* sp. 87) *Nomada* sp. 88) *Onychogonia* sp. 89) *Osmia* sp. 90) *Palpada vinetorum* 91) *Panurginus beardsleyi* 92) *Paravilla* sp. 93) Pepsinae 94) *Perdita Cockerellia* 95) *Perdita Hexaperdita* 96) *Perdita Perdita* 97) *Pholisora catullus* 98) *Phyciodes phaon* 99) *Poecilognathus* sp. 100) *Polistes* sp. 101) Pompilinae 102) *Pontia protodice* 103) *Protandrena Heterosarus* 104) Psenini 105) *Pyrgus communis* 106) *Pyrota* sp. 107) *Ravinia* sp. 108) *Scolia* sp. 109) *Sphaenothecus bivittatus* 110) Sphaeropthalminae 111) *Stenodynerus* sp. 112) *Stizoides renicinctus* 113) *Sydates* sp. 114) Tenebrionidae 115) *Thecophora* sp. 116) Tiphiinae 117) *Toxomerus* sp. 118) *Trichochrous* sp. 119) *Villa* sp. 120) *Zonitis* sp.

Figure IV.25 Bipartite networks illustrating flower visitation by bees in native grasslands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014. The top row is flowers designated by their USDA Plant Database symbol (USDA and NRCS 2017). The bottom row is the pollinators that visited the flowers.




1) *Agapostemon angelicus* 2) *Agapostemon angelicus/texanus* 3) *Agapostemon texanus* 4) *Ashmeadiella gilletei* 5) *Augochloropsis metallica* 6) *Bombus pensylvanicus* 7) *Calliopsis coloradensis* 8) *Colletes* sp. 9) *Diadasia diminuta* 10) *Diadasia enavata* 11) *Diadasia ochracea* 12) *Diadasia rinconis* 13) *Halictus ligatus* 14) *Halictus tripartitus* 15) *Lasioglossum* sp. 16) *Lasioglossum Dialictus* 17) *Lasioglossum Evylaeus* 18) *Lasioglossum Hexaperdita* 19) *Megachile parallela* 20) *Megachile policaris* 21) *Melissodes* sp. 22) *Melissodes communis* 23) *Melissodes coreopsis* 24) *Melissodes submenuacha* 25) *Melissodes tristis* 26) *Nomada* sp. 27) *Osmia* sp. 28) *Panurginus beardsleyi* 29) *Perdita Cockerellia* 30) *Perdita Hexaperdita* 31) *Perdita Perdita* 32) *Protandrena Heterosarus*

Table IV.22. Structural components and indices of plant-pollinator interaction networks involving insect orders Hymenoptera, Diptera, Coleoptera, and Lepidoptera of croplands, CRP and native grasslands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014.

| **Index** | **Cropland** | **CRP** | **Native Grassland** |
|---|---|---|---|
| a. number of invertebrate species | 129.0 | 80.0 | 120.0 |
| b. number of plant species | 35.0 | 40.0 | 58.0 |
| c. number of plant families | 14.0 | 13.0 | 20.0 |
| d. Shannon diversity | 4.634 | 4.794 | 5.144 |
| e. links per species | 1.457 | 1.525 | 1.461 |
| f. NODF (nested metric based on overlap and decreasing fill) | 8.47* | 8.46* | 5.85* |
| g. connectance | 0.053 | 0.057 | 0.037 |
| h. web asymmetry | -0.573 | -0.333 | -0.483 |

* $p < 0.001$

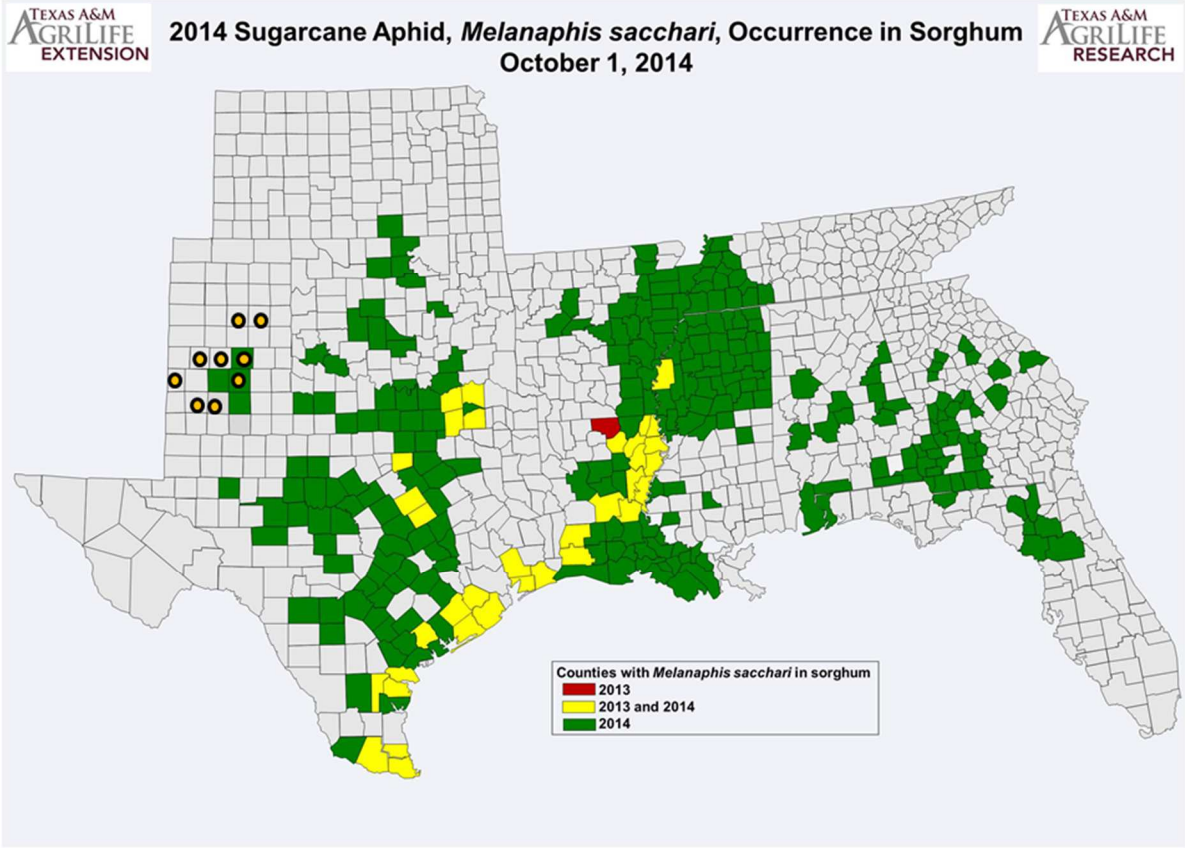
Table IV.23. Structural components and indices of plant-pollinator interaction networks involving bees of croplands, CRP and native grasslands in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Texas High Plains in 2013-2014.

| **Index** | **Cropland** | **CRP** | **Native Grassland** |
|---|---|---|---|
| a. number of invertebrate species | 31.0 | 19.0 | 32.0 |
| b. number of plant species | 21.0 | 20.0 | 34.0 |
| c. number of plant families | 11.0 | 8.0 | 14.0 |
| d. Shannon diversity | 3.993 | 3.485 | 3.868 |
| e. links per species | 1.177 | 1.077 | 1.061 |
| f. NODF (nested metric based on overlap and decreasing fill) | 15.84 | 11.06 | 9.58 |
| p value for NODF | p = 0.03 | p = 0.65 | p = 0.03 |
| g. connectance | 0.104 | 0.111 | 0.064 |
| h. web asymmetry | -0.192 | 0.026 | 0.030 |

Table IV.24. Flowering forbs and native grasses recommended for inclusion in a CRP seed mix. Selection based on sweep net data, plant presence in previous studies (Haukos and Smith 1997) and field guides (Lee-Mader et al. 2016, Holm 2017, NRCS 2017). Plants marked (x) are of special value to native bees or attract insects that prey upon insect pests, and *Cirsium ochrocentrum* (xx) also provides nesting materials for native bees as determined by The Xerces Society and the Lady Bird Johnson Wildflower Center. Plants marked (#) are legumes and should be included in a seed mix when possible because of their nitrogen fixing qualities.

| Plant | Bloom Time | Duration | Native Bees | Biological Control | Nitrogen fixing |
|---|---|---|---|---|---|
| **Seedbank** | | | | | |
| *Helianthus annuus* | J,A,S,O | Annual | x | | |
| *Helianthus ciliaris* | J,J,A,S,O | Perennial | x | | |
| *Coreopsis tinctoria* | A,M,J | Annual | | | |
| **Most visited** | | | | | |
| *Grindelia papposa* | A,S | Annual | x | | |
| *Grindelia squarrosa* | J,A,S | Annual | x | | |
| *Sphaeralcea coccinea* | A,M,J,J,A,S | Biennial | x | | |
| *Verbesina encelioides* | A,M,J,J,A,S,O | Annual | x | | |
| *Heterotheca stenophylla* | M,J,J,A,S,O | Perennial | | | |
| *Machaeranthera pinnatifida* | A,S,O | Perennial | | | |
| *Engelmannia peristenia* | M,A,M,J,J | Perennial | | | |
| *Hymenopappus flavescens* | M,J,J,A,S | Biennial | | | |
| *Ratibida columnifera* | M,J,J,A,S,O | Perennial | x | | |
| *Ratibida tagetes* | J,J,A,S | Perennial | | | |
| **Infrequently visited or in study site but not in transects** | | | | | |
| *Asclepias latifolia* | J,A,S,O | Perennial | x | x | |
| *Asclepias verticillata* | M,J,J,A,S | Perennial | x | x | |
| *Centaurea Americana* | M,J | Annual | x | | |
| *Dalea jamesii* | M,J,J | Perennial | x | | # |
| *Liatris punctata* | A,S,O | Perennial | x | | |
| *Heterotheca villosa* | M,J,J,A,S,O | Perennial | | | |
| *Machaeranthera tanacetifolia* | M,J,J,A,S,O | Annual | | | |
| *Cirsium ochrocentrum* | J,J,A | Biennial | xx | | |
| *Vernonia marginata* | J,A | Perennial | x | | |
| *Chaetopappa ericoides* | A,M,J,J,A | Perennial | | | |
| **Not present in study but recorded in region** | | | | | |
| *Achillea millefolium* | A,M,J,J,A,S | Perennial | x | x | |
| *Dalea purpurea* | J,J,A,S | Perennial | x | | # |
| *Monarda punctata* | A,M,J,J,A | Annual | x | x | |
| *Sphaeralcea angustifolia* | F,M,A,M,J,J,A,S,O,N | Perennial | x | | |
| *Sphaeralcea hastulata* | J,J | Perennial | x | | |
| *Berlandiera lyrata* | A,M,J,J,A,S,O,N | Perennial | | | |
| **Shrub** | | | | | |
| *Baccharis salicina* | M,J,J | Perennial | | | |
| *Desmanthus illinoensis* | M,J,J,A,S | Perennial | | | # |
| *Amorpha canescens* | J,J | Perennial | x | | |
| **Native grasses** | | | | | |
| *Bouteloua gracilis* | | Perennial | | | |
| *Bouteloua dactyloides* | | Perennial | | | |

Figure IV.26. 2013-2014 presence of sugarcane aphid in the Southern High Plains. Counties affected during the study were Briscoe and Floyd. Data from Texas A&M AgriLife Extension and Research (Texas A&M AgriLife Extension 2017a).



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VITA

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